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Original Article

Assessment of Regional Myocardial Displacement via Spectral Tissue Doppler Compared with Color Tissue Tracking

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Abstract

Background: *The recent developments in tissue Doppler imaging (TDI) now more than ever permit the quantification of the myocardial function. In the current systems, tissue tracking or displacement curves are generated from color tissue Doppler data through the instantaneous temporal integral of velocity-time curves.*

Methods: *The purpose of the present study was to assess regional myocardial displacement via spectral TDI. Maximum myocardial velocities were extracted from spectral pulsed tissue Doppler images using a developed computer program and were integrated throughout the cardiac cycle. Spectral tissue Doppler echocardiography was performed to evaluate longitudinal and radial functions in 20 healthy men, and the calculated end-systolic displacements were subsequently compared with the displacements measured from the same areas via color tissue tracking.*

Results: *According to the Bland-Altman analysis between spectral tissue tracking and color tissue tracking, the significant arithmetic mean was 7.34 mm with SD mean differences of ±2.24 mm in all of the evaluated segments. Despite significant differences ($p<0.001$), there was a good significant correlation between the two methods ($r=0.79$, $p<0.001$).*

Conclusion: *A verification study showed that the proposed approach had the ability to assess regional myocardial displacement using spectral TDI, which can be used in a wider range of equipment than is currently possible.*

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Keywords: *Ultrasonography, Doppler • Numerical analysis, computer-assisted • Diagnostic imaging*

Introduction

Tissue Doppler imaging (TDI), a new method in echocardiography for analyzing segmental myocardial function, demonstrates the velocity of a myocardium segment toward or away from the transducer.[1] Recent advances in science have ushered in new refinements such as tissue tracking, which has been validated by various studies. Tissue tracking curves are generated from tissue Doppler data through the instantaneous temporal integral of velocity-time curves.[2-5] This is displayed as the distance of motion or displacement along the Doppler axis throughout the cardiac cycle. Tissue tracking allows an assessment of the systolic displacement of different myocardial regions, visualized by a graded display of seven-color bands indicating the different distances of the systolic myocardial motion amplitude and tissue tracking curves.[6,7]

Spectral tissue Doppler velocities are obtained using pulsed Doppler, a method that provides a spectrum of velocities for each point at a time so that the maximum velocity can be chosen by measuring the outer border of the modal display. On the other hand, color tissue Doppler

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usesthe autocorrelation analysis when computing myocardial velocity, and can only compute one velocity for each sample volume at a time; this velocity is the mean of all velocity components found within the sample volume.[8] McCulloch et al. reported that color Doppler myocardial velocities underestimated spectral tissue Doppler velocities and such differences might result in interpretive errors. Since tissue tracking curves are generated from color tissue Doppler data, underestimating color Doppler may lead to underestimating tissue tracking data.[9]

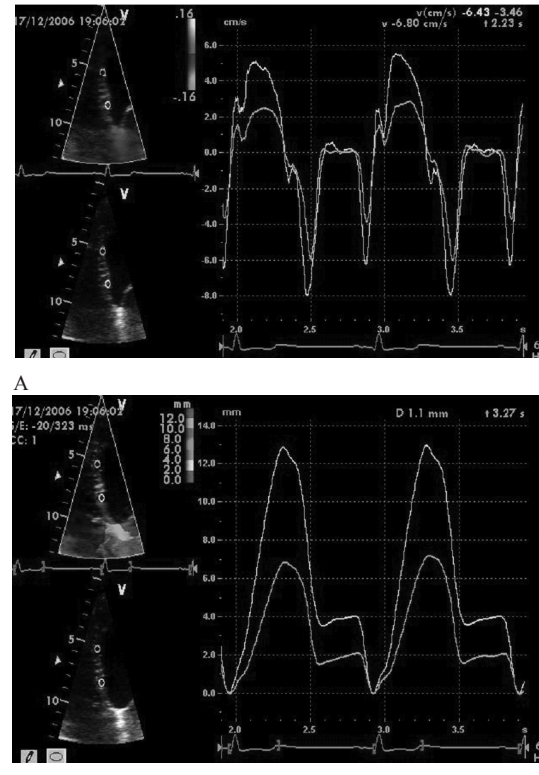
The present study suggests a computerized method for the evaluation of myocardial displacement using spectral TDI. This method relies on the computation of the area under the maximum velocity recordings, from which displacement measurement can be performed throughout the cardiac cycle.

Methods

Twenty healthy men between 29 and 50 years of age were included in the study. All of them had a normal physical examination, electrocardiograms, and echocardiography; and none of them had a history of cardiovascular disease, angina, hypertension, diabetes, and medication. Informed consent was obtained from all the subjects prior to their inclusion in the study.

Echocardiographic acquisition: Spectral and color tissue Doppler imaging: All the echocardiography studies were conducted with a Vivid 7 digital ultrasound scanner (GE, Milwaukee, WI, USA), equipped with an ergonomically-designed M3S transthoracic sector transducer with harmonic capability. The images were acquired with the subjects at rest and lying in the lateral decubitus position with data acquisition at end-expiration. Two-dimensional electrocardiograms were superimposed on the images. Standard two-dimensional echocardiography was performed on all the participants, and their ejection fractions were measured using Simpson>s biplane method. TDI was performed using standard transthoracic apical two- and four-chamber views and also para-sternal short axis view in the base and mid levels according to the guidelines of the American Society of Echocardiography.[10] For the apical views, care was taken to obtain the data by limiting the angle of interrogation in an attempt to align at as low a degree as possible to the longitudinal motion. For the para-sternal short axis views, care was taken to keep the anteroseptal and posterior left ventricular wall segments perpendicular to the ultrasound beam so that it would be aligned at zero degrees to radial motion. Color Doppler myocardial imaging (CDMI) and spectral pulsed TDI were performed by adjusting the signal filters until they reached a Nyquist limit of 16 cm/s and by using the minimum optimal Doppler gain settings to minimize the spectral broadening of the Doppler signals.

The CDMI raw data were recorded at a depth of 16 cm, frequency of 2.4 MHz, and frame rates of higher than 150 frames per second throughout two cardiac cycles and were stored digitally in a cine-loop format on the memory of the scanner. Off-line analysis was performed using quantitative analysis software so as to obtain the regional myocardial velocity. The digital 8-mm sample volume was placed within the myocardium wall thickness at the basal and middle segments of the interventricular septum and anterior walls in the apical views and also the basal and middle levels of the posterior wall in the para-sternal short axis views,[11] and the tissue velocity curves were subsequently acquired (Figure 1A). The integrals of the tissue velocity curves were thereafter calculated to create tissue tracking curves[12] (Figure 1B), and end-systolic displacements were measured for the two cardiac cycles.



A

B

Figure 1. Tissue Doppler imaging and velocity curves throughout two cardiac cycles from the base and mid segments of the septum wall in the four-chamber view (A) and displacement curves (color tissue tracking) calculated by integrating the velocity curves (B)

Spectral TDI was performed using an 8-mm pulsed Doppler sample volume, placed in the same locations as those for CDMI. The spectral TDI and CDMI patterns were characterized by isovolumic contraction and ejection phase (with positive polarity) during systole; and they were characterized during diastole by isovolumic relaxation, early diastolic (with negative polarity), and late atrial contraction velocities (with negative polarity), respectively[13] (Figure 1A and Figure 2A). The spectral tissue Doppler images were saved and were transferred to a personal computer for off-

line analysis via a program written in the Matlab software version 7.0.1 (Math Software Co., Matwork, USA) for evaluating regional myocardial displacement throughout the cardiac cycle. The outer borders or envelopes of the velocity spectrums were extracted automatically via this program based on color purity and were integrated by Simpson>s rule to create displacement curves. The curves were afterward employed to measure the myocardial displacements at end-systole, which were then compared with the displacements measured from the same areas via color tissue tracking. A block diagram of the program and the related images is presented in Figure 2.

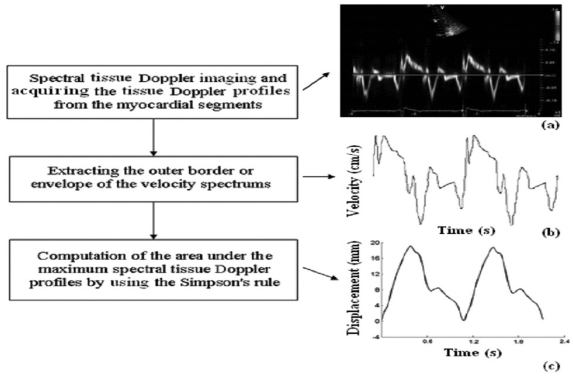


Figure 2. Block diagram of the presented method for the assessment of myocardial displacement using maximum spectral tissue Doppler data

Simpson's rule is well known for anyone attempting to work out a digitized signal. This method, instead of approximating function y=f(x) with straight line segments, can approximate with parabolas (Figure 3) before the area under the parabolas can be integrated. In Simpson's rule, the integral, $\int_a^b f(x)d(x)$ is approximated by:[14]

$$S = \frac{h}{3}(y_0 + 4y_1 + 2y_2 + 4y_3 + ... + 2y_{n-2} + 4y_{n-1} + y_n)$$

This approximation is based on a regular partition of [a, b] of size n, where n is even and h=(b-a)/n. The area under the Doppler velocity curve represents the time velocity integral (TVI) and is equal to the area enclosed by the Doppler velocity profile during one ejection period.[15] A method for the verification is to process the images of the spectral tissue Doppler with known TVI and assess the accuracy of the program by comparison. For this reason, we applied our program not only to the 70 spectral tissue Doppler images but also to the end-systolic TVI, determined manually by an expert echocardiologist. The results of the two methods were compared by correlation and the Bland-Altman[16] analysis.

All the data were expressed as mean±standard deviation (SD), and the comparisons between the differenceswere made using the paired samples t-test. Results were considered significant when the probability value was <0.05.

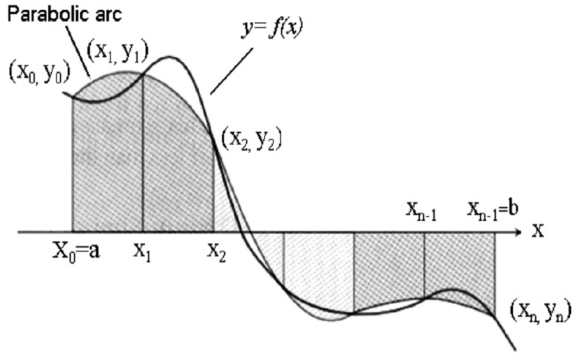


Figure 3. Simpson's rule by approximating function y=f(x) with parabolas and integrating the area under the parabolas. For i=0 to n, (xi, yi) shows coordinate of points

The correlation and Bland-Altman analysis with the 95% limit of agreement (i.e. mean difference±1.96 SD of the difference) were calculated to assess the relationships between the end-systolic displacements of the manual TVI and the presented methods and also to assess the relationships between the myocardial end-systolic displacements with the spectral and color tissue tracking methods. Intraobserver and interobserver variabilities were defined as differences between the two measurements and were expressed as a percentage error of the means. All the statistical analyses were performed using the SPSS software package (SPSS Inc. Chicago, IL, USA).

Results

The mean age of the participants was 43±9 years old. Their resting heart rates and echocardiographic ejection fractions varied between 62 and 79 beats per minute (mean=71±6 bpm) and 55 and 60% (mean=57.4±2.4%), respectively.

The statistical analyses showed no significant difference in terms of the end-systolic displacement between the results of the proposed program and manually traced TVI by an expert echocardiologist at 95% confidence level (p=NS). There was an excellent correlation between the results of the proposed program and the TVI acquired from 70 segments, comprised of 35 base segments (10 interventricular septum base, 13 anterior base, and 12 posterior wall base segments) and 35 mid segments (10 interventricular septum mid, 13 anterior mid, and 12 posterior wall mid segments). The coefficient correlation, correlation significance, and regression equation were r=0.99, p<0.001 and y=-0.122+1.004x, respectively (Figure 4A). For the Bland-Altman analysis, the difference between the two methods was plotted against the average of both observations. The Bland-Altman analysis revealed that there was no significant bias of 0.06 mm with the SD mean differences of ±0.38 mm in the evaluated segments between the end-systolic displacements using the proposed program and TVI (Figure 4B).

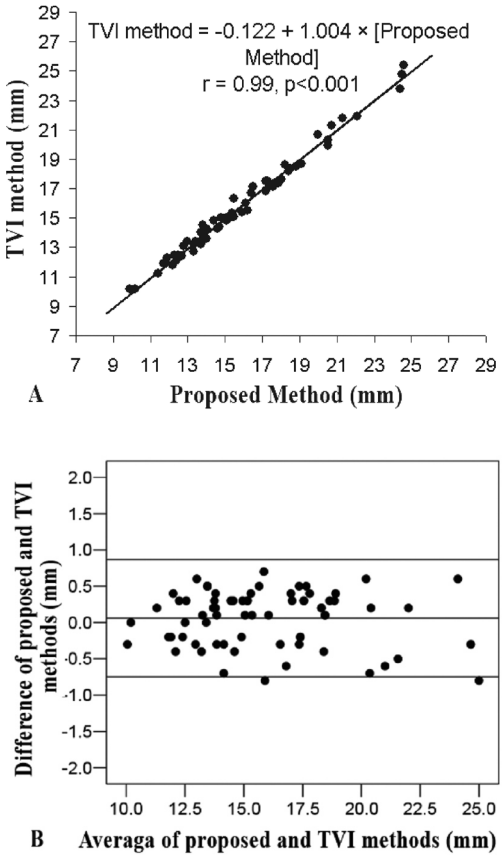


Figure 4. The correlation of the two end-systolic displacements that resulted from integrating the spectral tissue Doppler images acquired using the proposed program and manually traced time velocity integral (TVI), respectively (A) and the Bland-Altman graphs with 95% limit of agreement (B). The middle line indicates the average difference between the two methods, whereas the outer lines represent 1.96 SD or the 95% limit of agreement.

The results of the end-systolic displacements of the interventricular septum (18 base and 18 mid segments) and anterior (18 base and 16 mid segments) walls from the longitudinal assessment and posterior wall segments (18 base and 18 mid segments) from the radial assessment using the spectral and color TDI (spectral and color tissue tracking) are presented in Table 1. There were significant differences between the two methods at 95% confidence level in all the segments ($p<0.001$).

The statistical analyses showed a significant correlation between the displacements acquired using the spectral and color tissue tracking methods obtained from the 106 segments, comprising 54 base and 52 mid segments of the interventricular septum and anterior and posteriorwalls ($r=0.79$, $p<0.01$ and regression equation was $y=9.041+0.813x$) (Figure 5A). According to the Bland-Altman analysis, the significant arithmetic mean was 7.34 mm with SD mean differences of ±2.24 mm in all the evaluated segments (Figure 5B). The intraobserver and interobserver variabilities for the proposed method were found to be 3.4% and 4.3%, respectively; and there was no significant difference between the two measurements used for these calculations.

Table 1. End-systolic displacement (Mean±SD): Spectral tissue tracking versus color tissue tracking

Sample site	Spectral TT (mm)	Color TT (mm)	P-value
Septal base	20.98±2.27	11.94±1.26	<0.001
Septal mid	14.33±1.66	7.92±1.19	<0.001
Anterior base	17.59±1.88	12.21±1.44	<0.001
Anterior mid	13.79±2.41	7.17±1.19	<0.001
Total base	19.57±2.40	11.98±1.28	<0.001
Total mid	14.06±2.06	7.54±1.23	<0.001
Short axis base	17.16±1.54	9.13±1.30	<0.001
Short axis mid	14.73±1.26	6.88±0.93	<0.001

Spectral TT, Spectral tissue tracking; Color TT, Color tissue tracking; Total base, Mean values calculated from total base segments in longitudinal assessments; Total mid, Mean values calculated from total mid segments in longitudinal assessments

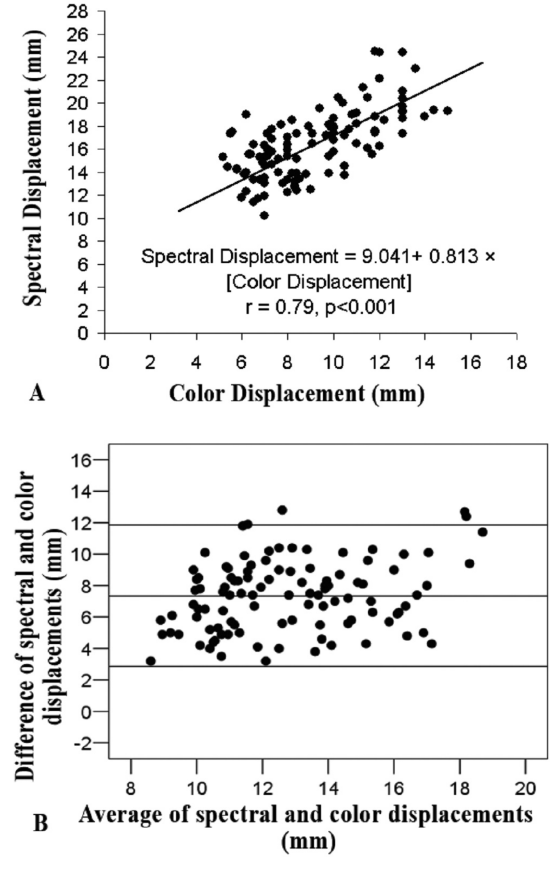


Figure 5. The correlation of the two end-systolic displacements using the spectral and color tissue tracking from the 106 base and mid evaluated segments combined (A) and the Bland-Altman graphs with 95% limit of agreement (B). The middle line indicates the average difference between the two methods, whereas the outer lines represent 1.96 SD or the 95% limit of agreement

Discussion

The color tissue tracking modality offers the possibility of gaining supplementary information on the myocardial function, and efforts have been made to utilize the imaging capability of the technique qualitatively in various clinical situations including dilated cardiomyopathy, left bundle branch block, myocardial ischemia, and cardiac resynchronized therapy studies.[17-21] We herein presented a computerized approach for the evaluation of myocardial displacement using spectral TDI. The method relies on the computation of the area under the maximum spectral tissue Doppler recordings, from which displacement measurement was made using the described program (Figure 2). In this program, we employed Simpson's rule in order to calculate the area under the curve. What is very important in the present context is the error in Simpson's rule, which is proportional to the fourth power of the subintervals. Simpson's rule, therefore, renders exact values for polynomial functions.[14] A practical capability in the presented method is the ability to measure myocardial displacement using the echo systems supplemented to spectral pulsed TDI, which can be used in a wider range of equipment than is currently possible. We verified accuracy by manually tracing the TVI of the spectral tissue Doppler images throughout the cardiac cycle and comparing the end-systolic displacements resulting from the methods.

This study was part of another one in which our aim was to carry out a longitudinal assessment of the myocardium in the left anterior descending artery at-risk regions. In this study, consequently, we chose the anterior and septum wall segments for longitudinal assessments as well as the posterior wall segments for radial assessments, because spectral Doppler signals are clearer than are the anteroseptal wall segments. The results of the color tissue tracking for the total base and mid segments (Table1) may be comparable with the myocardial displacement values of the mid and base segments, already defined in healthy individuals by Borges et al.[22] (11.98±1.28 mm in our study versus 12.5±2.02 mm for base and 7.54±1.23 mm in our study versus 8.5±1.99 mm for mid segments). We could not compare the presented spectral tissue tracking findings with the previous ones because they have not been reported previously.

The Doppler-based methods prevailed at the clinical stage, although these methods suffer from inherent limitations. TDI is a Doppler technique and, therefore, the limitations of Doppler measurements must also be applied to this method. First, one of the most important limitations of Doppler measurements is their angle dependence.[23-25] Storaa et al. investigated the impact of angular error in the apical two- and four-chamber views on measured velocities in a clinical setting. They sought to find out how large an angular mismatch could be accepted and their results showed that angular mismatch of up to 15 or 20 degrees gave acceptable velocity estimates and that the misalignment was very low in the mid segments.[23] In our study, even though we tried to perform accurate recordings of myocardial velocities by adequate alignment between the ultrasound beam and the main vector direction of wall motion, the angle errors for the anterior and septum base segments were almost 12±3 degrees and 6±2 degrees, respectively. Second, TDI has been widely used to quantify the regional myocardial function by measuring tissue velocities. However, the regional Doppler tissue velocities, consisting of spectral and color tissue Doppler methods in one area, are affected by the motion of the adjacent regions as well as the whole heart translational motion, which has been posed as a limitation of these techniques.[22,26,27]

We studied only healthy persons in the present study; it is important that the diagnostic capacity of such an analysis be evaluated for the detection or discrimination of significant heart disease. The work reported here should be considered the first step of the tissue tracking process using spectral TDI, and it could form the basis for further advances. We are currently exploring ways to utilize the data of the spectral TDI so as to perform such analyses more objectively and rapidly. The present findings have not been reported previously and may have some clinical relevance for assessing conventional or stress echocardiography by quantitative means.

Conclusions

It can be concluded from our experience that our proposed approach has the ability to assess regional myocardial displacement using spectral tissue Doppler images. Even though there was a significant difference between color and spectral tissue tracking, there was a good correlation between them. The differences between the presented method and the color tissue tracking method were predictable because as we mentioned in the introduction section, color tissue Doppler uses the autocorrelation analysis and the computed velocity is the mean of all the velocity components found within the sample volume,[9] whereas the spectral tissue tracking method described here uses the maximum component found within the sample volume.

Acknowledgments

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