Quantitative Evaluation of Regional Left Ventricular Function Using Three-Dimensional Speckle Tracking Echocardiography

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Abstract

Although 2D speckle tracking echocardiography (STE) has been shown useful for the assessment of regional left ventricular (LV) function, it is limited by its 2D nature. Our goal was to evaluate new 3D-STE software by comparing regional wall motion (RWM) measurements against 2D-STE, and testing its ability to identify RWM abnormalities. 2D and real-time 3D datasets obtained in 32 subjects were analyzed to measure radial, longitudinal and rotational indices of displacement and strain. Segments were classified as normal or abnormal using cardiac MRI. 3D-STE and 2D-STE indices did not correlate well and showed wide limits of inter-technique agreement despite the minimal biases. In normal segments, 3D-STE showed: (1) higher displacements, due the out-of-plane motion component; (2) smaller SDs, indicating tighter normal ranges; (3) gradual decrease in displacement and reversal in rotation from base to apex. In abnormal segments, all 3D-STE indices were reduced. In conclusion, this is the first study to evaluate the new 3D-STE technique for measurements of RWM indices and demonstrate its superiority over 2D-STE.

1. Introduction

The use of newly developed 3D speckle tracking echocardiography (3D-STE) allows tracking of the motion of ultrasound speckles within the 3D scan volume, irrespective of the direction of motion and thus could overcome the limitation of the previous 2D-STE [1]. Accordingly, the aims of this study were: (1) to compare 3D-STE against 2D-STE regional wall motion (RWM) measurements, including radial, longitudinal and circumferential displacement and strain, and (2) to test the ability of these indices to identify RWM abnormalities. To achieve these goals, a group of subjects with a wide range of LV function, undergoing 2D and real-time 3D echocardiographic (RT3DE) imaging was studied. Indices of RWM were compared between the two techniques. The ability of 3D-STE to differentiate normal and abnormal segments was assessed using cardiac magnetic resonance (CMR) images as a reference.

2. Methods

Forty-two subjects were screened. Ten subjects were excluded from the protocol because of inadequate endocardial visualization in the short-axis (SAX), or apical 2- and 4-chamber (A2C, A4C) 2D views in at least one segment. The remaining 32 subjects (age: 59±17 years; 20 men) were studied, including 9 normal volunteers, 11 patients with coronary artery disease, 10 with dilated cardiomyopathy and 2 with valvular disease. Additional exclusion criteria were: dyspnea precluding a 10-15 sec breath-hold, cardiac arrhythmias, pacemaker or defibrillator, claustrophobia and other known contraindications to CMR imaging.

2.1. Echocardiographic imaging

Echocardiographic imaging was performed using a Toshiba Artida 4D imaging system. First, 2DE images were obtained in the SAX, A2C and A4C views. Then, RT3DE datasets were acquired using the 3D transducer (PST-25SX) in the wide-angled "full-volume" mode. Temporal resolution was between 11 and 23 frames per cardiac cycle, depending on heart rate.

2.2. Magnetic resonance imaging

CMR images were obtained using a 1.5 Tesla scanner (Siemens). Steady-state free precession (true FISP) mode was used to acquire images using retrospective ECG gating and parallel imaging techniques during a 10-15 sec breath-hold with a temporal resolution of 30 frames per

cardiac cycle. Mid-ventricular SAX as well as apical 2-, 3- and 4-chamber views were reviewed by an expert reader who classified RWM in each segment as normal or abnormal.

2.3. Speckle tracking analysis

2DE images were analyzed using wall motion tracking software (Toshiba) by an experienced investigator blinded to the results of the 3D-STE measurements and the diagnosis. After manual initialization of the LV endocardial border at end-diastole, contours were tracked automatically frame-by-frame. In each view, the left ventricle was automatically divided into 6 segments using standard segmentation. Endocardial contours were manually adjusted when necessary to optimize boundary position and tracking.

Pyramidal RT3DE datasets were analyzed using the 3D wall motion tracking software (Toshiba) by an investigator blinded to the results of the 2D-STE measurements and the diagnosis. A2C and A4C views as well as three SAX views at different levels of the left ventricle were automatically selected at end-diastole. LV endocardial boundaries were manually initialized in two apical views. Then, the 3D endocardial surface was automatically reconstructed, tracked in the 3D space throughout the cardiac cycle and manually adjusted, when necessary. The ventricle was automatically divided into 16 3D segments using standard segmentation.

Finally, radial and longitudinal displacements and rotation, as well as radial, longitudinal and circumferential strains were automatically calculated for each segment. Displacement in 3D space was calculated only for 3D-STE. Peak value of each index was defined as its maximum absolute value with the sign.

2.4. Statistical analysis

3D-STE and 2D-STE derived indices of regional LV function were compared. Comparisons included linear regression with Pearson correlation coefficients and Bland-Altman analyses to assess the bias and limits of inter-technique agreement. The significance of the biases was tested using paired two-tailed t-tests. In addition, to test the variations in the 3D-STE indices from base to apex, each index was averaged separately for basal, mid-ventricular and apical segments. Differences between the LV levels were tested using one-way ANOVA for independent samples.

Moreover, to determine the ability of 3D-STE analysis to differentiate between normal and abnormal RWM, these indices were averaged separately for normal and abnormal segments, and the differences were tested using unpaired t-test. P-values <0.05 were considered significant.

3. Results

Figure 1 depicts the difficulty with the interpretation of RWM using 2D-STE images due to considerable variability in the color patterns caused by the inability to capture the out of plane motion.

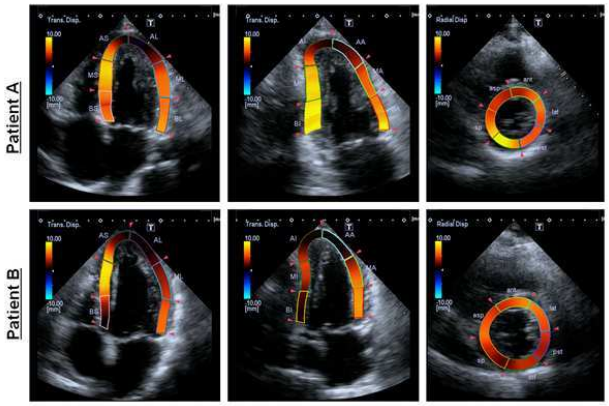

Figure 1. End-systolic 2D-STE images obtained in a subject with normal LV function (top) and a patient with hypokinetic apex due to ischemic heart disease (bottom): A4C (left), A2C (middle) and SAX (right) views. Radial displacement is superimposed: red colors represent the inward displacement, blue the outward.

The 2D slices extracted from end-systolic 3D-STE datasets obtained in the same two subjects are shown in Figure 2 with 3D displacement color-encoded. In the normal subject, color patterns are considerably more uniform compared to the 2D-STE images in Figure 1, consistent with normal RWM. In contrast, the color pattern in the patient with ischemic heart disease is less uniform, depicting a darker area in the apical lateral wall, extending towards LV base and the inferior wall.

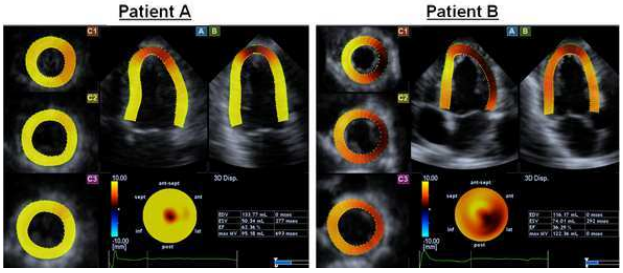

Figure 2. End-systolic 3D-STE images obtained in the same two subjects as in figure 1. 3D displacement information is shown in color overlays superimposed on the gray-scale. Color map is the same is in figure 1.

Figures 3 and 4 show the results of the comparisons between the segmental 2D-STE and 3D-STE values of the six indices of RWM obtained in the entire study group. 3D-STE indices of RWM did not correlate well with 2D-STE values as reflected by r-values between

0.16 (for rotation) and 0.76 (for longitudinal displacement). Although biases were minimal, the limits of agreement were wide (2SD: 5-6 mm and 14° for displacements and 17-52% for strains), indicating that measurements obtained using these two techniques are not interchangeable in individual patients.

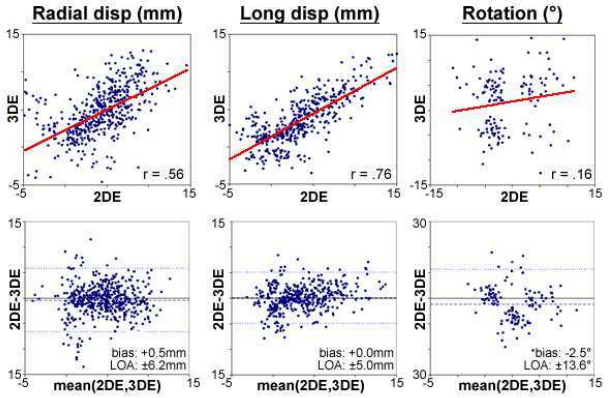

Figure 3. Results of linear regression (top) and Bland-Altman (bottom) analyses for segmental values of radial (left) and longitudinal (middle) displacements and rotation (right) obtained in 32 study subjects.

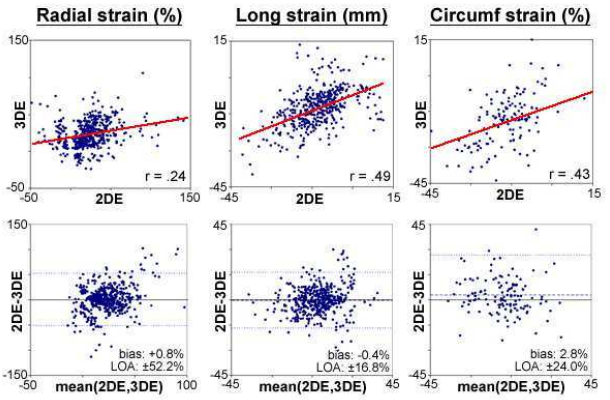

Figure 4. Results of linear regression (top) and Bland-Altman (bottom) analyses for segmental values of radial (left), longitudinal (middle) and circumferential (right) strain values obtained in 32 study subjects.

The expert classification of segments resulted in 339 normal and 173 abnormal segments. In the normal segments, comparisons of 2D-STE and 3D-STE derived indices (figure 5, top) showed that 3D-STE displacement values were higher, although the difference in the longitudinal displacement was not significant. In addition, the SDs of 3D-STE measurements were smaller for all six indices, especially relative to the measured mean values, indicating tighter normal ranges than those of 2D-STE values. Separate 3D-STE analysis of normal basal, mid-ventricular and apical segments (figure 5, bottom left) demonstrated a gradual decrease in radial and longitudinal displacement and reversal in direction of rotation from base to apex, which was significant in all comparisons. Inter-level differences in strain showed more complex patterns (figure 5, bottom right).

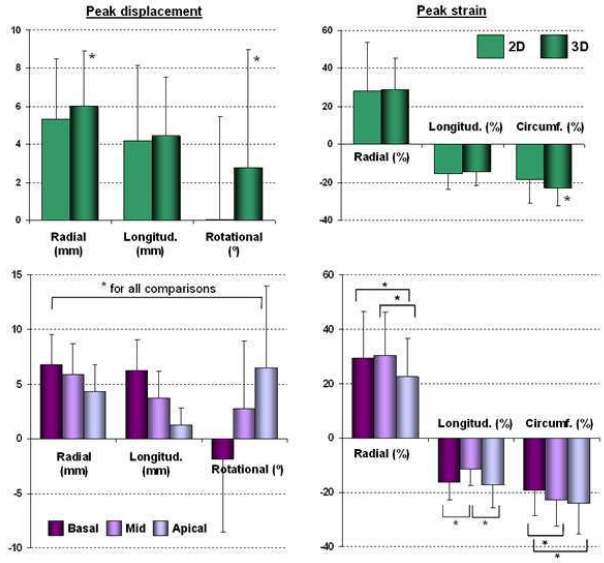

Figure 5. Results of the comparisons between 2D-STE and 3D-STE measurements of indices of regional wall motion: radial and longitudinal displacement and rotation (top, left) and radial, longitudinal and circumferential strain (top, right). Results of separate analysis of the 3D-STE indices of regional wall motion calculated in the normal segments at three different LV levels: radial and longitudinal displacement and rotation (bottom, left) and radial, longitudinal and circumferential strain (bottom, right).

The comparisons between normal and abnormal segments showed that all 3D-STE indices were reduced in the abnormal segments (Table 1). These differences reached significance in all indices with the exception of rotation.

Table 1. Results of the comparisons between normal and abnormal segments for the 3D-STE indices of regional wall motion. * - p<0.05, unpaired two-tailed t-tests.

	Normal	Abnormal
Longitudinal disp. (mm)	6.0±2.9	2.9±2.7*
Radial disp. (mm)	4.5±3.1	2.4±2.5*
Rotation (°)	1.3±7.3	0.5±5.3
Longitudinal strain (%)	28.8±16.4	12.0±14.8*
Radial strain (%)	-14.3±7.3	-9.5±7.0*
Circumferential strain (%)	-21.5±9.9	-10.2±9.9*

4. Discussion and conclusions

A variety of quantitative techniques for the evaluation of global and regional LV function have been used in an attempt to overcome the subjective nature of visual interpretation of LV dynamics. RWM has been commonly assessed using Tissue Doppler imaging, which is limited by its angle dependence. Recently, STE, which is angle-independent, has been found useful in quantifying regional LV function, using parameters such as myocardial strain [2,3] and LV motion patterns [4,5], and dyssynchrony [6,7]. However, 2D-STE is intrinsically limited by its 2D nature, because it can only track motion occurring within the imaging plane, while the out of plane motion component results in noise and interferes with tracking. This inability affects the accuracy of the displacement vector estimates and thus of the derived indices of RWM. Accordingly, we hypothesized that the novel 3D-STE technique [1] could allow more accurate measurements of regional LV displacement and strain.

The relatively low levels of inter-technique agreement found in this study showed that 2D-STE and 3D-STE measurements are not interchangeable in individual patients, despite the small biases. We postulated that this was due to the fact that 3D-STE is not limited to one imaging plane, and as a result can better describe the complex 3D motion of the LV walls. This hypothesis was supported by the homogeneous color distribution in normal ventricles, consistent with expected normal patterns of LV wall motion (figure 2, patient A) and the improved ability to localize RWM abnormalities using 3D-STE images (figure 2, patient B). Moreover, in normal segments, 3D-STE demonstrated larger magnitude of displacement (figure 5), reflecting the ability to register all three components of the motion vector, as opposed to the 2D-STE single-plane analysis. The relatively smaller normal variability of the 3D-STE compared to 2D-STE measurements (figure 5, top) provided additional support to the superiority of 3D-STE in handling the complexity of 3D RWM.

Importantly, our results also demonstrated that the new 3D-STE technique is sensitive enough to: (1) quantify differences in motion patterns between different LV levels (figure 5, bottom), which, unlike the 2D-STE methodology, can be assessed by analyzing a single dataset; and (2) accurately separate normal and abnormal segments using multiple quantitative indices (Table 1).

Two limitations of the 3D-STE technique are the relatively low temporal and spatial resolution, both affecting the accuracy of endocardial tracking and leading to suboptimal results in a considerable proportion of segments.

This is the first study to evaluate a variety of 3D-STE derived indices of LV RWM and demonstrate the advantages of this new technique over 2D-STE measurements. With the benefits gained by the addition of the third motion component, which remains invisible to both TDI and 2D-STE techniques, this new technique may become the method of choice for the assessment of regional LV function.

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