

Effect of Cardiac Resynchronization Therapy on Longitudinal and Circumferential Left Ventricular Mechanics by Velocity Vector Imaging: Description and Initial Clinical Application of a Novel Method Using High-Frame Rate B-Mode Echocardiographic Images

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Cardiac resynchronization therapy (CRT) has emerged as an important method to treat patient with symptomatic heart failure with evidence of intraventricular dyssynchrony. Tissue Doppler imaging by echocardiography has been shown to be an excellent tool for the assessment of mechanical left ventricular dyssynchrony and the selection of patients for CRT. However, there are some patients who do not show symptomatic improvement following CRT. One possible explanation for this is the need to optimize not only longitudinal synchrony, but also improve the circumferential and radial dynamics of the left ventricle. Doppler imaging does not allow reliable assessment of the latter because of the angle-dependency of the technique. Velocity Vector Imaging (VVI) is a newer technique which is angle-independent and thus provides an avenue to evaluate short-axis mechanics of the left ventricle. We describe a case in which VVI was used to assess the left ventricular dynamics in a patient with heart failure who did not respond to CRT. (ECHOCARDIOGRAPHY, Volume 22, November 2005)

echocardiography, resynchronization, velocity, vector

Background

Cardiac resynchronization therapy (CRT) using biventricular pacing (BiVP) is based on the premise that correction of mechanical dyssynchrony in a patient with heart failure (HF) and left ventricular (LV) systolic dysfunction improves pump function and alleviates symptoms.¹⁻⁴ Although QRS complex duration of >130 ms on surface electrocardiograms (ECG)

have been used as a measure of dyssynchrony, Doppler tissue imaging (DTI) by echocardiography is a more sensitive tool.^{5,6} DTI has been shown to be a useful method to measure dyssynchrony at baseline and after CRT using various indices, all of which essentially describe the longitudinal mechanics of the heart as a pump. Up to 30% of patients undergoing CRT may not manifest hemodynamic or symptomatic benefit.^{7,8} Among the factors that may account for the lack of response one possibility is that, the radial and circumferential mechanics of the heart may not be improved although the longitudinal synchrony may have been restored by CRT.^{9,10}

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Doppler tissue imaging is fraught with problems in the assessment of radial and circumferential mechanics of the LV due to the inherent angle dependency of the technique. Newer methods that do not rely on Doppler, instead tracking ultrasonic speckle have the advantage of directionally unconstrained imaging of the myocardial motion.¹¹ Velocity vector imaging (VVI) is one such approach that allows measurement of myocardial velocity and deformation in the apical and short-axis views of the LV. We describe a case in which VVI was used to study the effect of CRT on longitudinal and circumferential myocardial function.

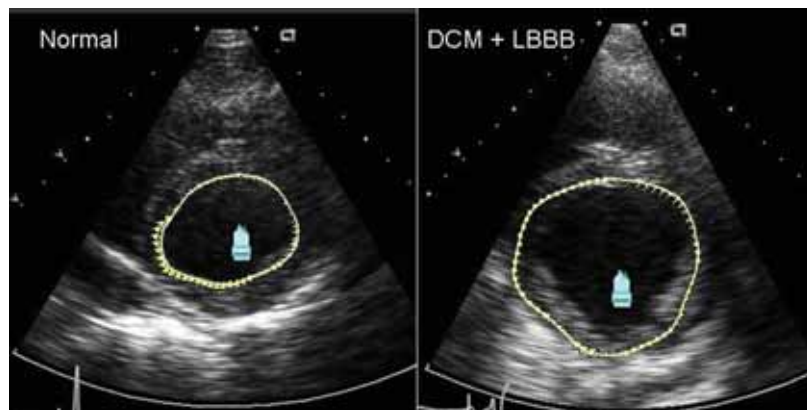
VVI uses a tracking algorithm to estimate myocardial velocity at a set of points on a contour in a sequence of two-dimensional sequence of B-mode images. The velocity is displayed as a vector overlaid onto the B-mode image where the length of the vector indicates the magnitude of the tissue velocity, and the direction of the vector indicates the direction in which the tissue is moving. The velocity vector is a composite of both the points on the contour (Lagrangian component) and the velocity of the points orthogonal to those points (Eulerian component).¹² The borders are not “detected,” instead they are “tracked,” or followed in time, starting from one reliable existing instantaneous trace drawn by the operator over one single frame. Using this method, assessment of the local frame-to-frame displacement is equivalent to evaluation of the local velocity (ratio between displacement and time interval). The automatic evaluation of the velocity at a point is determined by comparing the displacement of the image data about such a point in two consecutive frames. This sophisticated tracking algorithm is not a simple “speckle tracking” algorithm and instead uses specific reference points including the mitral annulus, motion of the tissue/cavity border, motion of the tissue near the border and

periodicity of the heart motion over the R-R intervals. VVI utilizes whole heartbeat analysis using Fourier techniques as well as constraints on the global coherence of the tracked geometry.

Methods

We describe a case in which VVI and DTI were used to study the longitudinal, circumferential, and radial mechanics of the LV in a patient with HF who underwent biventricular pacing (BiVP) and automated implantable cardioverter-defibrillator (AICD) placement. *Clinical History:* A 62-year-old man with HF secondary to nonischemic dilated cardiomyopathy in NYHA III functional status and on optimal medical therapy (including a diuretic, an angiotensin-converting enzyme (ACE) inhibitor and a beta-blocker) was referred for BiVP and AICD implantation. *EKG* showed sinus rhythm and left bundle branch block (LBBB) with a QRS duration of 174 ms. *Baseline echocardiography* was done using an Acuson Sequoia ultrasound system (Siemens, MountainView, CA) system and 4V1c transthoracic transducer. Standard clinical imaging protocol revealed a dilated LV with an end-diastolic volume of 224 ml, LV internal diastolic dimension of 7.2 cm and an ejection fraction of 22% as measured by the modified Simpson’s method. There was moderate tricuspid regurgitation and normal right ventricular systolic function. *DTI* was performed using the tissue Doppler mode with the Doppler velocity range set between 16 and 20 cm/sec to prevent color aliasing. The imaging sector was narrowed to image the region of interest, for example, in the apical four-chamber (A4C) view the sector was narrowed to selectively and separately image the septum and lateral wall. DTI was done in all three standard apical views at a temporal resolution of

Figure 1. Myocardial tracking algorithm based on manually identified endocardial border in the short-axis (SAX) view of the left ventricle (LV). The picture on the left is from a normal volunteer and that on the right is from a patient with dilated cardiomyopathy (DCM), heart failure (HF), and left bundle branch block (LBBB).



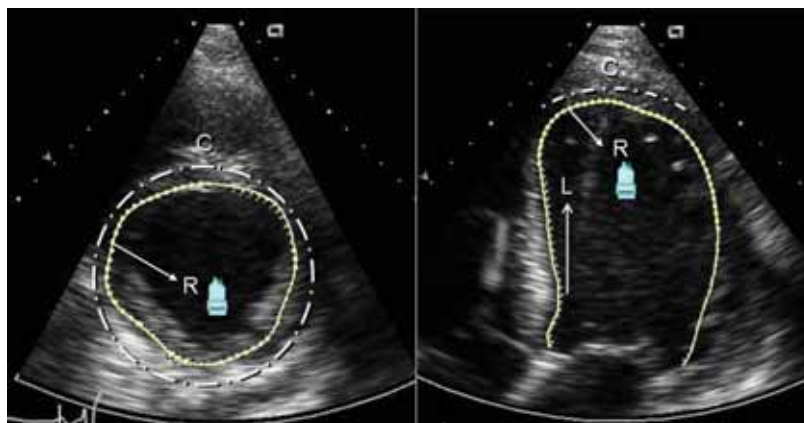


Figure 2. Myocardial tracking in the SAX and apical 4C views from a patient with DCM, HF, and LBBB velocity. Velocity vector imaging (VVI) yields data on radial and circumferential dynamics in the SAX view and in the 4C view provides data on longitudinal, radial, and circumferential dynamics of the LV. R = radial velocity, C = circumferential strain/strain rate, and L = longitudinal velocity, strain, and strain rate.

~ 119 Hz. A region of interest was placed and tracked through one cardiac cycle at the mid-septum and the mid/basal lateral wall in the A4C view; in the mid-anterior and basal-inferior walls in the apical two-chamber view, and the basal septum and mid-posterior wall in the apical long-axis view. Time to peak myocardial velocity (msec) was measured from the velocity-time curves; this data was also displayed in color M-Mode. VVI was done in the parasternal short axis (SAX) view below the papillary muscle level (apex) at a tempo-

ral resolution of ~ 100 Hz. Endocardial borders were manually identified (Fig. 1) in a single frame of a cine-loop and the borders in other frames were automatically generated with the ability for the operator to alter any of those contours. VVI measured radial velocity and circumferential strain in the SAX view (Figs. 2 and 3). Cardiac resynchronization and AICD were done by placing leads in the right atrium, right ventricle, and the lateral vein of the coronary sinus and connecting them to a cardioverter-defibrillator (InSync Marquis,

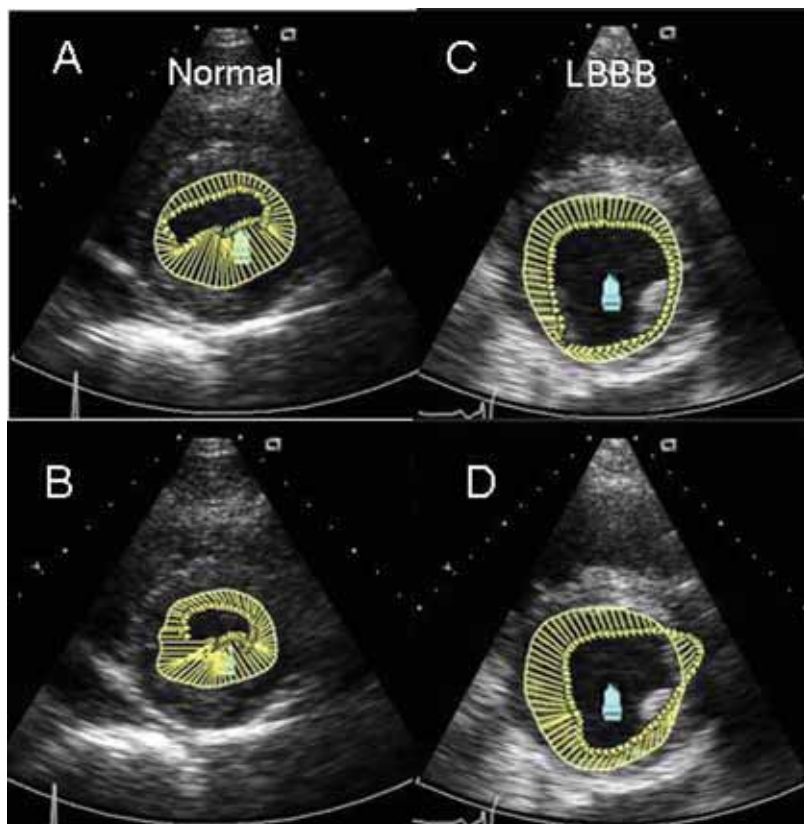


Figure 3. Radial velocity vectors in the apical SAX view from a normal (left panel) and a patient with LBBB (right panel). In the normal patient, in early/mid systole (A) and in late/end systole (B) the radial vectors are of similar magnitude and direction. In LBBB, in early/mid systole (C) the septal vectors are of higher magnitude than lateral radial velocities, in late systole (D) the septal vectors have peaked whereas the lateral wall vectors are directed in the opposite direction (dyssynchronous).

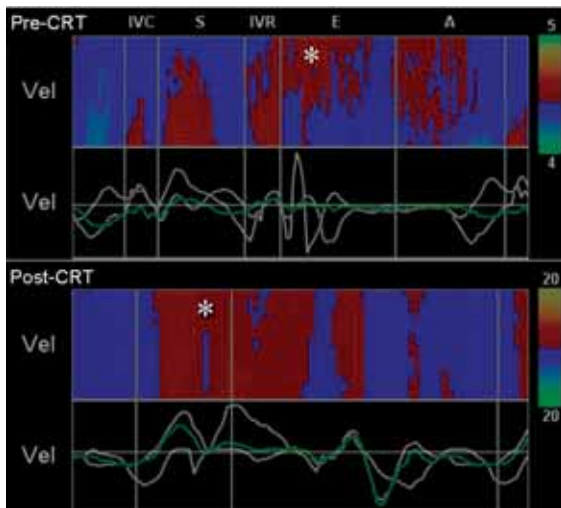


Figure 4. Doppler tissue imaging data from the patient with LBBB, pre- and post-biventricular pacing. The top panel shows peak myocardial velocities in the lateral wall are reached in diastole (*), whereas the maximal septal velocity is reached in systole. Post-biventricular pacing, the velocities in the two regions (asterisk represents the lateral wall) are reached in systole with improved synchrony of longitudinal motion.

Medtronic). Atrio-ventricular synchronization was optimized by Doppler echocardiography.

Results

The clinical recovery of the patient post-BiVP was uneventful. The symptoms of dyspnea improved within 2 weeks of the procedure. The improvement, however, was not sustained as the patient's symptoms of dyspnea returned to the baseline level at 1 month and the functional class returned to NYHA Class III. The estimated LV ejection fraction improved marginally to 25% at 2 weeks after BiVP but showed no further improvement at 1 month. The LV end-

diastolic internal dimension decreased to 6.9 cm in the first month after the procedure.

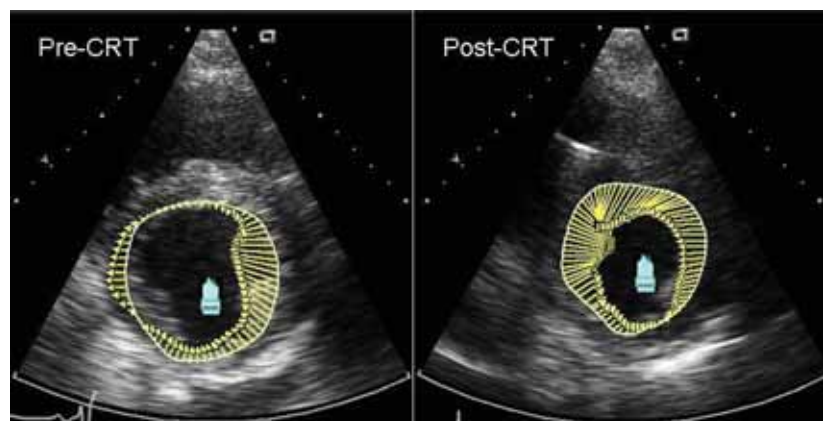
DTI of the septal and lateral walls post-BiVP showed significant synchronization of the time to peak velocity, 247 ± 32 and 400 ± 89 msec, respectively at baseline versus 184 ± 35 and 235 ± 35 msec, respectively post-BiVP (Fig. 4). VVI showed synchronization of septal and lateral wall radial velocity vectors as shown in Figure 5. At baseline, the time to peak radial velocity for the basal and mid-lateral wall was 357 msec and 502 msec, respectively. Post-BiVP, the time to peak radial velocities were 231 and 191 msec for basal and mid-lateral wall (Fig. 6). Circumferential strain which is also shown in Figure 6, peaked at 723 ± 98 msec at baseline (range: 610–785 msec) and 481 ± 227 msec (range: 210–770 msec) post-BiVP.

Discussion

This case illustrates the importance of measuring radial and circumferential myocardial function when assessing the outcome of CRT after BiVP in patients with HF with evidence of mechanical dyssynchrony. Our VVI data show that in this patient while synchrony of longitudinal myocardial contraction was significantly improved by BiVP, circumferential myocardial function was not optimized. This may explain the partial and transient improvement in clinical symptoms and status.

Current data, while strongly supporting the benefits of CRT in patients with HF and LBBB also highlight the fact that up to 30% do not show beneficial symptomatic and/or hemodynamic response. Among the various factors which may influence this, is the notion that optimization of radial and circumferential myocardial dynamics by CRT may also be important. Doppler myocardial imaging has been valuable in our ability to measure long-axis

Figure 5. VVI data from the SAX view of the same patient. The radial velocities in the lateral wall peak in late systole/early diastole prior to biventricular pacing. After biventricular pacing, the septal and lateral wall radial velocities are synchronous. Thus, cardiac resynchronization therapy (CRT) has improved radial myocardial contraction synchrony.



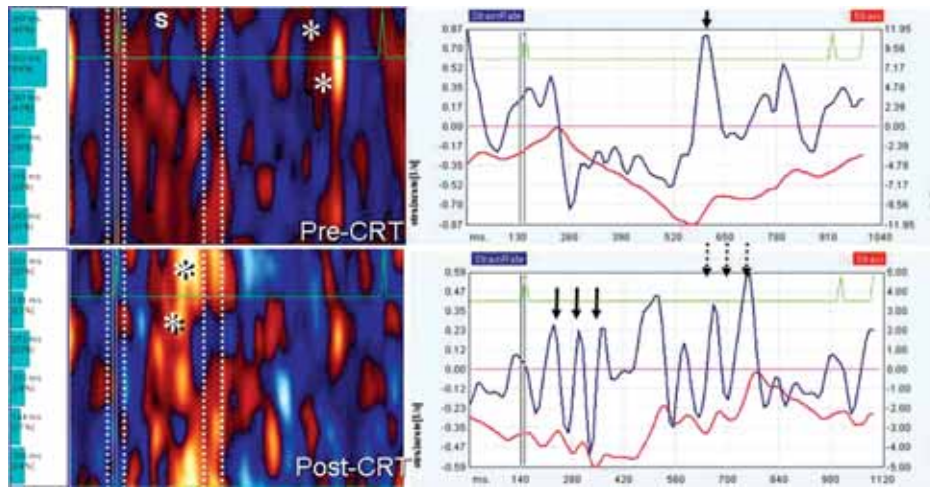


Figure 6. Radial velocity (left panel) and circumferential strain and strain rate (right panel) in an M-Mode and graphic display, respectively. The time to peak radial velocity of basal and mid-lateral wall (asterisks) is improved after CRT. However, the time to peak circumferential strain and strain rate data in the right panel shows marked heterogeneity in the time to peak strain and strain rate even after CRT (arrows). S = systole.

myocardial function. Indeed, a number of studies have shown the value of DTI evaluation of regional mechanical dyssynchrony at baseline and its response to CRT.^{5,6} However, the long-axis function assessment does not account for the effects of BiVP on the circumferential and radial function of the myocardium. The latter is not only a critical determinant of the long-axis function but also of LV ejection. There is relative paucity of data that describe the effects of CRT on radial and circumferential dynamics that are components of LV torsional deformation.

This case illustrates the point that although longitudinal and radial velocities of the LV were synchronized, VVI showed persistent heterogeneity of circumferential strain, which may be a possible basis of the nonsustained improvement in LV systolic performance and the overall lack of symptoms of dyspnea in this patient.

Conclusion

VVI is a unique tool, which is able to describe both longitudinal and short-axis mechanical function of the LV and may be valuable in better assessing the outcome of CRT.

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