The Role of Echocardiography in the Assessment of Mechanical Dyssynchrony and Its Importance in Predicting Response to Prognosis After Cardiac Resynchronization Therapy

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The aim of this review is to synthesize the published evidence regarding the benefits of identifying mechanical asynchrony before implantation of biventricular devices, and the role of echocardiography in the identification and quantification of mechanical asynchrony. It summarizes the published studies addressing the several echocardiographic parameters of dysynchrony that have already proven to predict response to cardiac resynchronization therapy. M-mode echocardiography, Doppler tissue imaging, strain and strain rate imaging, tissue tracking, and 3-dimensional echocardiography parameters of dysynchrony shown to be able to identify responders are discussed. In addition, the prognostic implication of the identification of mechanical asynchrony before implantation is addressed. A summary of the published evidence of the echocardiographic parameters able to identify patients more likely to derive a prognostic benefit is provided. Finally, it mentions some of the current uncertainties and possible future applications of echocardiographic evaluation of dysynchrony. (J Am Soc Echocardiogr 2007;20:91-99.)

RATIONALE AND BENEFITS OF CARDIAC RESYNCHRONIZATION THERAPY

Heart failure (HF) is a major burden in industrialized countries. The prevalence of symptomatic HF in Europe ranges from 0.4% to 2%.1 In the United States, HF strikes approximately 5 million patients and more than 550,000 are diagnosed with HF each year.2 Despite our best understanding of its pathophysiologic mechanisms and the recent advances in pharmacologic therapy, it remains a high-mortality and morbidity disease.1,2

About 30% to 50% of patients with HF have concurrent electrical delay in the surface electrocardiogram (ECG), mainly in the form of left bundle branch block (LBBB).3 This ventricular conduction disturbance, which changes left ventricular (LV) contraction patterns resulting in dyssynchronized intraventricular (within the LV) and interventricular (in respect to right ventricle [RV]) contraction, further impairs systolic performance.3,4 Some of the mechanical consequences of this electrical disorder are further reductions in cardiac output and diastolic filling time, and increases in LV wall stress, LV end-systolic volume (LVESV), and mitral regurgitation.3,4

The rationale that biventricular pacing stimulation could synchronize contraction of and between the two ventricles led to extensive investigation on the possible role of pacing in the therapy of this disease.5-10 Evidence of the clinical benefits of cardiac resynchronization therapy (CRT) is now documented in several multicenter randomized clinical trials.5-8 Initial CRT trials5,6 have clearly shown an improvement of symptoms, exercise capacity, quality of life, ventricular function, and LV remodeling in patients with severe systolic dysfunction and QRS prolongation who remain symptomatic despite optimal medical therapy. The MUSTIC trial7 was a single-blind randomized controlled trial that enrolled 67 patients with severe HF, normal in sinus rhythm, and a QRS duration longer than 150 milliseconds. Patients were randomized to 3 months of active pacing or 3 months of inactive pacing followed by crossover therapy. Active biventricular pacing was associated with significant increases in the distance walked in 6 minutes, quality-of-life score, and peak oxygen uptake, and with fewer HF hospitalizations. The MIRACLE trial8 was a multicenter trial that randomized 453 patients with HF, a
LV ejection fraction (EF) of 35% or less, and a QRS interval of at least 130 milliseconds to biventricular pacing or no pacing. During a 6-month follow-up period there was a significant increase in the 6-minute walking distance, quality of life, New York Heart Association (NYHA) functional class, and time on treadmill during exercise testing in the resynchronization group. A significant improvement in LVEF and LV end-diastolic diameter was also observed, as was reduction in hospitalizations.

More recently, two large randomized trials have also shown that CRT can confer a survival benefit in these patients. The COMPANION trial included 1520 patients with ischemic and nonischemic cardiomyopathy in NYHA functional class III to IV, a LVEF less than 35%, and a QRS interval of 120 milliseconds or longer. Patients were randomly assigned in a 1:2:2 ratio to receive: optimal medical therapy alone; optimal medical therapy and CRT; or optimal medical therapy, CRT, and an implantable cardioverter defibrillator. During a mean follow-up of 16 months, CRT, alone or in combination with an implantable defibrillator, significantly reduced the composite end point of death from or hospitalization for any cause. A reduction in the secondary end point of death from any cause was also observed, but failed to reach statistical significance with CRT alone (hazard ratio [HR] 0.76, 95% confidence interval 0.58-1.01, \( P = 0.059 \)). The CARE–HF trial was the first study to demonstrate a consistent survival benefit with CRT. In this study, 813 patients with HF in NYHA class III or IV, QRS duration of 120 milliseconds or longer, and LVEF of 35% or less were included and randomly assigned to medical or resynchronization therapy. During a mean follow-up of 29.4 months, CRT significantly reduced the combined end point of death from any cause or hospitalization for a major cardiovascular event (HR 0.65, \( P < 0.001 \)). Moreover, death from any cause was also significantly reduced with CRT (HR 0.64, \( P < .002 \)).

Meta-analyses have already demonstrated a 51% reduction in HF-associated mortality and a 29% reduction in hospitalizations with CRT and, more recently, a 32% reduction in HF hospitalizations and a 21% reduction in all-cause mortality. Based on the substantial body of evidence available, CRT is currently a class I recommendation in patients with LVEF 35% or less, in sinus rhythm, and ventricular dyssynchrony (QRS width \( \geq 120 \) milliseconds), who remain symptomatic (NYHA class III-IV) despite optimal medical therapy, to improve symptoms (NYHA class III-IV) despite optimal medical therapy, to improve symptoms (level of evidence A), reduce hospitalizations (level of evidence A), and reduce mortality (level of evidence B). Furthermore, in a recent study, the results showed that only the presence of LBBB was an independent predictor of interventricular asynchrony but none of the classic echocardiographic parameters was found as a predictor of intraventricular asynchrony. Thus, a specific evaluation of cardiac asynchrony should be performed.

**ECHOCARDIOGRAPHIC EVIDENCE OF DYSSYNCHRONY PREDICTS RESPONSE TO CRT**

The QRS width is, currently, the approved selection criterion for implantation of these devices. However, about 30% of these patients do not respond to CRT and show no evidence of reverse remodeling. On the other hand, the presence of mechanical asynchrony was documented in patients with narrow QRS, and these patients were also shown to derive a favorable effect from CRT. Thus, it seems that asynchronous contraction can be present without substantially increasing the QRS duration on the surface ECG. Attempts to identify and quantify mechanical asynchrony directly, rather than relying solely on QRS prolongation, lead to the investigation of the possible role of echocardiography. M-mode and Doppler echocardiography, Doppler tissue imaging (DTI), strain and strain rate, tissue tracking, real-time 3-dimensional echocardiography, and their ability to identify dyssynchrony have been studied. Using these conventional and sophisticated echocardiographic techniques several echocardiography parameters were extensively investigated and, today, some of them have clearly been shown to be able to predict response to CRT.

**M-MODE ECHOCARDIOGRAPHY**

The septal-to-posterior wall-motion delay (SPWMD) was proposed by Pitzalis et al as a parameter of intraventricular dyssynchrony. It is determined as the shortest interval between the maximal posterior displacement of the septum and the maximal displacement of the left posterior wall in an M-mode tracing from the parasternal short-axis view at the level of the papillary muscle. In a group of 20 patients with advanced HF and LBBB, the SPWMD significantly correlated with reverse remodeling after CRT. It was able to identify responders, defined as patients with a LVEFSV index reduction of at least 15%, with a specificity of 63%, a positive predictive value of 80%, and an accuracy of 85% during a 4-week follow-up period. More recently, in a study designed to evaluate long-term outcome that will be mentioned in appropriate section of this review, the SPWMD has again been proven to be able to predict response in 60 patients with CRT. An improvement in LVEF was observed in 79% of patients with a baseline SPWMD of 130 milliseconds or longer and in 9% of those with an SPWMD of less than 130 milliseconds during a mean follow-up of 14
months. The presence of echocardiographic LV asynchrony predicted an improvement in LVEF of greater than 5% with a sensitivity of 92% and a specificity of 78%.

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**DOPPLER ECHOCARDIOGRAPHY**

Pulsed Doppler flow measurements have been used to identify interventricular dyssynchrony. LV and RV pre-ejection intervals are measured as the time from the onset of the QRS complex on the surface ECG and the onset of the LV and RV pulsed Doppler waves. Interventricular dyssynchrony is evaluated by determining the extent of interventricular mechanical delay (IVMD), measured as the time difference between LV and RV pre-ejection intervals. An IVMD of more than 40 milliseconds is considered indicative of interventricular dyssynchrony but its ability to predict response to CRT remains to be proven. In a recent work by Waggoner et al., the Doppler-derived LV filling parameters have been shown to be an important predictor of long-term clinical outcomes after CRT and that in patients with ischemic cardiomyopathy there is a lack of improvement in LV diastolic function despite favorable effects on LV systolic performance.

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**DTI**

DTI allows measurement of regional myocardial velocities and their relation to electrical activity. The septal-to-lateral delay, a DTI index proposed by Bax et al., is measured as the time difference from the onset of the QRS complex and peak systolic DTI wave between the basal septal and lateral walls, and has been proven to be able to identify responders. In 25 consecutive patients with advanced HF and QRS duration longer than 120 milliseconds, the septal-to-lateral delay was the only predictor of acute improvement in LVEF and the only variable that differed between responders and nonresponders. Response was defined as a 5% or more increase in LVEF after CRT, and a septal-to-lateral delay of 60 milliseconds or longer was able to accurately identify responders.

In a more recent work, Bax et al. again demonstrated the ability of DTI echocardiographic evidence of LV dyssynchrony to predict response to CRT. In 85 patients with end-stage HF, QRS prolongation, and LBBB, LV dyssynchrony was defined as the maximum delay between peak systolic DTI velocities among the anterior, inferior, septal, and lateral LV basal walls. Interventricular dyssynchrony was assessed as the delay between peak systolic DTI velocity of the RV free wall and the LV lateral wall. Clinical response was defined as an improvement in NYHA class by one or more and an improvement by 25% or greater in 6-minute walking distance. Reverse remodeling was defined as a 15% or greater reduction in LVESV. The LV dyssynchrony, but not the interventricular dyssynchrony, was the only variable at baseline that was significantly different between responders and nonresponders. An optimal cut-off value of 65 milliseconds for LV dyssynchrony yielded a sensitivity and specificity of 80% to predict clinical improvement and of 92% to predict LV reverse remodeling during a 6-month follow-up. In this study, the authors also documented an ability to predict prognosis that will be discussed later.

DTI was also used by Penicka et al. in the demonstration that the degree of intraventricular and interventricular asynchrony and their combination were the best predictors of LV functional recovery and reverse remodeling after CRT in 49 patients with HF and QRS prolongation. Response was defined as a 25% or more increase in LVEF at 6-month follow-up. Electromechanical coupling time was measured by DTI at the LV basal lateral, septal, and posterior walls, and in the basal lateral segment of RV, as the time interval between the onset of QRS complex and the onset of regional velocity of myocardial shortening. Intraventricular asynchrony was calculated as the difference between the longest and the shortest electromechanical coupling time in the 3 basal LV segments. Interventricular asynchrony was calculated as the difference between electromechanical coupling times in the RV segment and the most delayed from the 3 LV segments. A combined index of intraventricular and interventricular asynchrony was calculated by adding both parameters. All 3 indexes of mechanical asynchrony accurately predicted positive LV remodeling in response to CRT.

The value of a DTI-derived systolic asynchrony index (TS-SD) has been investigated in several studies by Yu et al. in patients with HF and ischemic or idiopathic dilated cardiomyopathy and wide or mildly prolonged QRS complexes. This index, calculated as the SD of the time to peak myocardial systolic contraction of 12 LV segments in a 6-basal-6-midsegmental model, was the only independent predictor of LV reverse remodeling after CRT. A preimplantation TS-SD of 32.6 milliseconds was able to totally separate nonresponders from responders, defined as a reduction in LVESV by greater than 15% 3 months after CRT, independent of the cause and the degree of QRS prolongation.

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**STRAIN, STRAIN RATE, AND TISSUE TRACKING**

Strain rate imaging is a novel developed variation of DTI that provides a high-resolution evaluation of regional myocardial function. Strain is defined as the change in distance between two points divided by the
initial length and strain rate is defined as the change in instantaneous velocity between two points divided by the instantaneous distance between those points. Negative strain rate represents active contraction whereas positive values represent relaxation or lengthening. It can identify postsystolic contraction and differentiate active myocardial contraction from passive displacement. Tissue tracking visualizes segmental systolic longitudinal motion amplitude and allows identification of delayed contraction.

In a comparison between DTI and strain rate imaging by Yu et al, the former showed to be superior on the prediction of reverse remodeling. Eighteen parameters of intraventricular and interventricular asynchrony, based on the time to peak myocardial contraction and time to peak strain rate, were compared along with postsystolic shortening in both ischemic and nonischemic groups. The TS-SD was the most powerful predictor of reverse remodeling in both groups. The postsystolic shortening of 12 segments was a good predictor only for the nonischemic group, and parameters of strain rate and interventricular asynchrony failed to predict reverse remodeling. More recently, the authors reported the use of tissue synchronization imaging (TSI) in the evaluation of 56 patients with CRT. Regional wall delay in TSI-coded 2-dimensional images and time to regional peak systolic velocity (Ts) in the 6-basal-6-midsegmental model were evaluated. Four parameters of systolic asynchrony were computed: the SD of Ts of the 12 LV segments; the SD of Ts of the 6 basal segments; the maximal difference in Ts between any of the 12 segments; and the maximal difference in Ts between any of the 6 basal segments. These parameters were assessed first only in ejection phase and, then, also including postsystolic shortening when it occurred. Severe lateral wall delay was able to predict reverse remodeling. Among the 8 parameters of asynchrony, the predictive values were higher for those measured in ejection phase than in postsystolic shortening. The SD of Ts of the 12 LV segments in ejection phase was the most powerful in predicting reverse remodeling and absolute gain in EF. This study has also demonstrated the excellent correlation between the systolic asynchrony index derived from DTI and that derived from TSI in ejection phase. The authors suggested that the identification of significant wall delay in TSI images can be indicative of a high likelihood of a reverse remodeling response. In the absence of a lateral wall delay, the measurement of the SD of Ts of the 12 LV segments in ejection phase is recommended, and a value above 34.4 milliseconds is likely to predict response. In a new article, these authors enhance the superiority of tissue velocity parameters of systolic asynchrony over displacement and strain mapping–derived parameters in predicting LV remodeling response after CRT. A recent study by Dohi et al investigated the use of echocardiographic strain imaging to quantify radial mechanical dyssynchrony in 38 patients who underwent CRT. Dyssynchrony was defined as the time difference of peak radial strain in the septum versus the posterior wall, and was significantly greater in patients with acute hemodynamic responses to CRT. A value of 130 milliseconds or more, when combined with a favorable LV lead position, was able to predict an immediate improvement in stroke volume with 95% sensitivity and 88% specificity.

Breithardt et al studied 34 patients with HF by echocardiographic phase analyses of LV wall motion with semiautomated endocardial border contour detection. They demonstrated that the difference between the lateral and septal wall-motion phase angles was able to predict acute increases in $dP/dt$ after CRT. The presence of baseline asynchrony, indicated by a lateral-septal difference greater than 25 degrees, was able to predict a contractile function benefit from CRT.

Tissue tracking was used by Sogaard et al in 25 patients with CRT and QRS prolongation and it demonstrated that the extent of the LV base circumference displaying delayed longitudinal contraction, before pacemaker implantation, was able to predict long-term efficacy of CRT. The beneficial effects included significant reductions in end-diastolic and systolic volumes and a significant increase in LVEF during a mean 12.6-month follow-up. In a strain rate analyses study by Capasso et al delayed longitudinal contraction, expressed either by time duration or percent of the basal segments, was the best among several intraventricular asynchrony indexes in predicting increases in LVEF after CRT.

**THREE-DIMENSIONAL ECHOCARDIOGRAPHY**

Real-time 3-dimensional echocardiography is a novel technique currently being investigated in the evaluation of patients with CRT. A pyramidal volume of the LV over a cardiac cycle is acquired and the full-volume data set is analyzed offline using a semiautomated endocardial contour anal-

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**Figure A**, Three-dimensional echocardiography analysis showing regional volumetric curves before cardiac resynchronization therapy (CRT) device implantation. Curves allow calculation of time taken to reach minimum regional volume for each segment as percentage of cardiac cycle. **B**, Same curves after CRT device implantation.
ysis. A dynamic endocardial reconstruction of the LV is performed subdividing it into color-coded segments. A time volume curve representing LV global and regional volume changes over the cardiac cycle is plotted. By assessing and displaying global and regional LV contraction and its timing throughout the cardiac cycle in a form that can be easily measured, it allows an accurate evaluation of LV segmental contraction patterns. In a recent study by Kapetanakis et al., a systolic dyssynchrony index (DI) was derived from these regional volumetric curves by calculating the time taken to reach minimum regional volume for each segment as a percentage of the cardiac cycle (Figure and Videos 1 and 2). The DI was defined as the SD of these timings. Higher values denote increasing intraventricular dyssynchrony. In 26 patients who underwent CRT, the DI significantly decreased after CRT in responders, along with clinical and echocardiography evidence of reverse remodeling. This was not the case in nonresponders. Responders were identified as those with higher DI values before implantation comparing with nonresponders, in which mean DI before implantation was much lower, revealing a lesser degree of significant dyssynchrony.

In conclusion, extensive investigation in this field resulted in several echocardiographic parameters that have been proposed to define dyssynchrony. Those mentioned in this review have already proven to be able to predict response to CRT, and this is of paramount importance. In fact, CRT is a widely accepted nonpharmacologic approach and it is imperative not only to select patients more likely to respond, but also to limit the risks of an invasive procedure in patients who are unlikely to benefit. On the other hand, the wide diversity of parameters, the variety of aspects of the synchronicity of contraction evaluated in the different parameters, the different definitions of response used in the several studies, and the small number of patients included can somehow explain our current inability to find a gold standard parameter to be used in clinical practice. In fact, one of the most interesting findings of the RAVE study was exactly the very poor agreement among the different methods to detect asynchrony. In this registry, the prevalence of intraventricular asynchrony was very variable depending on the method and criteria used to define it, and it ranged from 20.8% to 72.8% in patients with narrow QRS and from 26.2% to 79.6% in patients with prolonged QRS. Future large randomized clinical trials are needed to evaluate these proposed parameters and find accurate and standardized echocardiographic evaluation criteria of dyssynchrony.

PROGNOSTIC IMPLICATIONS OF ECHOCARDIOGRAPHIC EVIDENCE OF DYSSYNCHRONY

One of the most important features of a beneficial therapeutic strategy is its ability to positively influence prognosis. The preimplantation echocardiographic evidence of mechanical asynchrony is not only able to identify patients more likely to respond, but has recently also been shown to be an independent predictor of outcome. Thus, the presence of mechanical asynchrony seems to have prognostic implications. It not only identifies responders, but is also able to identify those patients most likely to derive a prognostic benefit with CRT.

Pizalis et al. studied 60 patients with severe HF and LBBB and demonstrated that the presence of a SPWMD of 130 milliseconds or longer, before CRT implantation, was able to prospectively identify those candidates who showed a significant reduction of HF progression, defined as a combination of death, hospitalization for worsening HF, or need for a sustained increase in HF medication, during a mean 14-month follow-up period. When CRT was given to patients with a SPWMD of 130 milliseconds or more, it reduced the HF-worsening events to a greater extent than in those with no evidence of dyssynchrony before CRT.

Bader et al. demonstrated that the presence of intraventricular, but not interventricular, asynchrony, assessed by DTI, was an independent predictor of hospitalization for cardiac decompensation in 104 patients with HF without myocardial infarction, independent of LVEF and QRS width. In this study, the electromechanical interval, defined as the time from the onset of the QRS complex on the surface ECG and the onset of the systolic DTI wave, was determined for the septal, inferior, lateral, and anterior walls. Intra-LV electromechanical delay was defined as the time difference between the shortest and longest electromechanical intervals among the 4 LV basal walls. The presence of intraventricular asynchrony, defined as an intra-LV electromechanical delay above 40 milliseconds, was strongly associated with a higher risk of early HF-worsening episodes requiring hospitalization.

In a previously mentioned study by Bax et al., preimplantation echocardiographic evidence of LV dysynchrony, defined as the maximum delay between peak DTI velocities among the anterior, inferior, septal, and lateral LV basal walls, was associated with a significant better prognosis in the first year after CRT. Patients with a value of 65 milliseconds or greater showed a lower event rate, defined as death and hospitalization for HF, as compared with a 50% event rate in patients with a value less than 65 milliseconds.

Fauchier et al. analyzed intraventricular and interventricular asynchrony by phase analysis of radionu-
kle angiography in 103 patients with nonischemic cardiomyopathy. Interventricular dyssynchrony was evaluated with the difference between LV and RV mean phase angles and intraventricular dyssynchrony was measured as the SD of the mean phase angle for the ventricular blood pools. The investigators demonstrated that increased intraventricular, but not interventricular, dyssynchrony was shown to be an independent predictor of major cardiac events, defined by cardiac death or worsening HF leading to heart transplantation, during a mean follow-up of 27 ± 23 months. Although not an echocardiographic study, the selective end point of cardiac death or transplantation, the number of patients included, and the duration of follow-up makes it worthy to be mentioned in this review, as a new insight on the prognostic importance of dyssynchrony.

In the CARE–HF study,8 there was a trend for a greater benefit of CRT in patients with a higher degree of interventricular asynchrony, shown by a lowering of the HR on the primary end point with an increasing IVMD. The HR on the primary end point of death from any cause or hospitalization for a major cardiovascular event in patients with an IVMD of 49.2 milliseconds or greater was 0.50 (95% confidence interval 0.36-0.70), whereas in patients with an IVMD of less than 49.2 milliseconds a value of 0.77 (95% confidence interval 0.58-1.02) was observed. Until now, no CRT trial has been specifically designed to address the prognostic implications of mechanical asynchrony. We need large randomized clinical trials to clarify whether the identification of dyssynchrony, either intraventricular or interventricular, can help us to select those patients most likely to obtain a survival benefit.

**UNSOLVED ISSUES IN MECHANICAL ASYNCHRONY EVALUATION**

We currently still discuss whether mechanical asynchrony actively contributes to the pathophysiologic process of systolic dysfunction or whether it is simply a marker of dysfunctional hearts and HF progression.3 Because it is important to correct the underlying mechanism responsible for a negative impact in systolic performance, it is imperative to find what kind of dyssynchrony best contributes to worsen performance and, thus, make the response to CRT more likely to occur.

We currently do not know which of the proposed echocardiographic parameters best define dyssynchrony. In addition, although studies have proposed cut-off values able to predict response for each of the parameters studied, the fact is that there is still no definite parameter or cut-off value that allows us to simply select and/or exclude CRT candidates in everyday clinical practice. There is still no agreement on which parameter should be included in baseline evaluation, and a standardized evaluation criteria is needed.4 We await the results of the ongoing PROSPECT study,33 designed to evaluate predictors of response to CRT. In this prospective multicenter trial, several conventional echocardiographic and DTI parameters will be tested and their ability to predict response will be evaluated. This, and further future studies that will surely come, will hopefully bring new insights into the echocardiographic evaluation of dyssynchrony.

Finally, it has been proposed that CRT provides the greatest hemodynamic benefit when applied to the most delayed LV site.33–35 Echocardiographic evaluation of dyssynchrony could contribute to the optimization of CRT efficacy, by identifying the most dysynchronous LV segment.4 Several DTI and 3-dimensional echocardiographic studies35–37 are investigating the possible role of echocardiography in the process of selection of the optimal pacing site.

**FINAL CONSIDERATIONS**

HF remains a major cause of death and disability in our countries, despite the proven morbidity and mortality benefits of pharmacologic therapy, including β-blockers, angiotensin-converting enzyme inhibitors, and spironolactone. Our HF population is likely to increase, not only because of increasing life expectancy, but also because cardiology is being increasingly successful in the process of saving failing hearts. CRT was proposed as a nonpharmacologic alternative therapy in these patients, and it has come a long way in the last decade. From the early evidence of clinical and functional benefit, it now shows it can also increase survival in these patients. Scientists found that not all patients responded positively to CRT and wanted to find out why. We found that echocardiographic evidence of dyssynchronous contraction could help us predict a positive response to CRT. Echocardiography has been advancing with amazing speed and has already found several parameters able to identify responders. Several new and sophisticated echocardiographic techniques are evolving, trying to overcome some limitations present in several conventional parameters. We need large multicenter randomized clinical trials and await the results of ongoing ones to find a simple, accurate, and widely applicable echocardiographic evaluation of CRT candidates.

**REFERENCES**

1. Swedberg K, Cleland J, Dargie H, Drexler H, Follath F, Komajda M, et al; Task Force for the Diagnosis and Treatment of Chronic Heart Failure of the European Society of Cardiol-


SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at 10.1016/j.echo.2006.07.004.

VIDEO LEGENDS

Video 1, Time-volume curves of the 17 volume segments of the left ventricle pre-CRT.

Video 2, The same curves as Video 1, but post-CRT.