Cardiac Resynchronization Therapy Devices: Patient Management and Follow-Up Strategies

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Results of numerous clinical trials support the use of cardiac resynchronization therapy (CRT) for treatment of moderate to severe heart failure in patients with cardiac dyssynchrony. Commercial approval of various CRT devices has led to a growing number of patients receiving this form of therapy. Patients with implanted CRT devices require specific attention to detect adverse events related to the device, detect failure to respond to therapy, and optimize device function. Interaction between the primary care physician, cardiologist, heart failure specialist, and electrophysiologist/implanting physician is necessary to accomplish these goals. Recognizing the signs and symptoms of adverse events or suboptimal response allows the primary care physician to alter drug therapy or, when appropriate, refer the patient to the heart failure specialist or electrophysiologist for optimization of CRT device programming or further intervention.

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Cardiac resynchronization therapy (CRT) delivered through biventricular pacing improves functional status and symptoms and reduces hospital utilization in patients with left ventricular (LV) dysfunction, congestive heart failure (CHF), and cardiac dyssynchrony caused by ventricular conduction disease.[1–3] Use of an implantable cardioverter-defibrillator (ICD) in combination with cardiac resynchronization reduces all-cause mortality in heart failure patients with ventricular dyssynchrony.[4] The commercial approval of CRT and

combined CRT-ICD systems has already led to the implantation of more than 50,000 devices, with an implantation rate that approximates 3000 implants per month in the United States (Guidant and Medtronic marketing departments, personal communication, April 2003). Indications for CRT include New York Heart Association (NYHA) Class III or IV CHF symptoms, reduced left ventricular ejection fraction (LVEF), and ventricular conduction system disease manifesting as QRS prolongation on the surface electrocardiograph (ECG) exceeding 120 ms. As the number of patients with CRT devices increases, practitioners need to familiarize themselves with the indications of this therapy, preparation of the patient designated to receive CRT, and specific issues affecting the follow-up care of patients receiving CRT.

Optimal management of the CRT patient involves an interaction between the primary care physician (PCP), cardiologist, electrophysiologist, and heart failure specialist. Identification of the proper CRT candidate begins with the PCP or cardiologist and often involves referral to a heart failure specialist or directly to an implanting physician. The electrophysiologist or implanting physician performs the procedure and handles device programming and device-related complications during follow-up. The heart failure specialist, in conjunction with the PCP, prepares the patient for the implantation procedure and continues long-term follow-up after implantation to adjust the management plan according to the outcome of CRT in each patient. Follow-up usually consists of scheduled office visits, echocardiography, CRT device interrogation, reprogramming of device setting, and medication adjustments. Some centers include cardiopulmonary exercise testing as part of routine follow-up.

The addition of tissue Doppler imaging to the echocardiographic examination may better characterize dyssynchrony and predict which patients are more likely to respond to CRT.

Evidence from clinical trials suggests that 25%–30% of patients who receive CRT do not respond to the therapy.[1–3] Reasons for this failure to respond include insufficient ventricular dyssynchrony at baseline, overriding comorbidities that attenuate the benefit of CRT, failure to resynchronize LV function because of inadequate lead implant, and suboptimal device programming. Maximizing the benefit of CRT requires appropriate patient selection; a good implantation technique that reduces complications and resynchronizes ventricular function; and a patient follow-up strategy that detects and manages adverse events, identifies nonresponders and the causes of failed response, and implements measures to correct the causes of failed response.

Patient Selection

Currently accepted inclusion criteria for selecting patients for CRT employ the ECG as the determinant of cardiac dyssynchrony. Setting the ECG criteria for dyssynchrony at a QRS duration of greater than 150 ms detects mechanical dyssynchrony with great specificity but may exclude potential responders with QRS durations of 120–150 ms. Setting the QRS duration threshold at 110 ms or 120 ms may include patients with ventricular dyssynchrony that is insufficient to allow a response to CRT. The ongoing Cardiac Resynchronization in Heart Failure (CARE-HF) trial is using imaging modalities to detect mechanical evidence of cardiac dyssynchrony in an effort to increase the specificity of response to CRT.[5] The use of standard two-dimensional echocardiography with Doppler sampling and M-mode examination usually detects the presence of ventricular dyssynchrony.[6] The addition of tissue Doppler imaging to the echocardiographic examination may better characterize dyssynchrony and predict which patients are more likely to respond to CRT.[7]

Overriding comorbidities may attenuate the response to CRT and the long-term impact of CRT on hospitalization and mortality. Severe lung disease, peripheral vascular disease, renal dysfunction, and pulmonary hypertension with right ventricular failure may overcome any potential effect of biventricular pacing on LV function.

Clinical trials demonstrating the benefit of CRT on CHF symptoms and functional status have included patients with stable CHF symptoms who were receiving optimal therapy and were able to complete a battery of diagnostic tests as part of the pre-enrollment evaluation. Exclusion criteria omitted patients with significant medical problems that precluded completion of pre-implantation screening and baseline evaluation. Furthermore, approximately 90% of subjects included in these trials fell into NYHA Class III designation; only 10% had Class IV symptoms.

A series of inpatients at Emory University who were receiving intravenous inotropic therapy at

the time of CRT device implantation had poor long-term results, with a 1-year mortality of 70%.[8] Therefore, CRT should be considered for the stable patient with NYHA Class III symptoms or stable Class IV symptoms. One should proceed cautiously when considering CRT for patients with severe or decompensated CHF. Results from clinical trials obtained in a relatively stable population should not be extrapolated to severely ill and unstable CHF patients. The compromised patient carries an increased risk of implant-related complications and may not obtain the same benefit from CRT.

Patient Preparation Prior to CRT Device Implantation

Proper preparation of patients for CRT device implantation includes optimization of pharmacologic therapy, achievement of a stable euvolemic state, management of anticoagulation therapy to reduce peri-procedural bleeding and thrombotic complications, and education of the patient as to the nature and risk of the implantation procedure. Numerous clinical trials suggest that optimal medical therapy for patients referred for CRT includes ACE inhibitors or angiotensin II receptor blockers (ARBs), β-blockers, diuretics, and spironolactone. Careful attention to volume overload decreases the likelihood of developing CHF during the implantation procedure. Excessive diuresis and volume depletion exposes the patient to the nephrotoxic risk of contrast administration or hypotension during the procedure. The patient who requires long-term warfarin therapy may discontinue the drug 4 to 5 days before the procedure. When appropriate, admission for intravenous heparin may reduce the risk of thromboembolism. Aggressive use of heparin after the implantation procedure increases the risk of hematoma and bleeding. Initiation of warfarin the day after the procedure, without the use of heparin, provides adequate anticoagulation for most patients.

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Device Selection: CRT-Defibrillator or CRT-Pacemaker

Commercially approved CRT devices include the CRT-pacemaker (CRT-P) and the CRT-defibrillator (CRT-D). Both devices use biventricular pacing to resynchronize the heart and improve symptoms, functional status, and other clinical parameters in patients with CHF. Only the CRT-D provides protection against sudden cardiac death; not surprisingly, only the CRT-D combination reduced all-cause mortality when tested in clinical trials. Data from the Multicenter Automatic Defibrillator Implantation Trial II (MADIT-II) showed that the ICD reduces all-cause mortality in patients with LV dysfunction and previous myocardial infarction.[9] The absolute reduction in all-cause mortality exceeded 30% in patients with QRS durations greater than 150 ms. The Comparison of Medical Therapy, Packing and Defibrillation in Heart Failure (COMPANION) trial demonstrated a reduction in all-cause mortality with CRT-ICD use in patients with CHF and LV dysfunction resulting from coronary artery disease or idiopathic cardiomyopathy.[4] The patient and physician may opt for CRT with or without ICD therapy. When a clinical indication for ICD therapy exists, a decision to forego ICD implantation in favor of CRT-P should be made in the context of a discussion of the relevant data supporting its use.

Implantation Procedure

The implantation of LV pacing leads to deliver CRT involves the following steps: obtaining venous access, inserting the right atrium and right ventricle leads, locating and entering the coronary sinus, selecting a target LV vein, advancing the pacing lead to the targeted site, and removing the implantation tools. A successful CRT device implanter possesses an understanding of the anatomy of the failing heart and the coronary veins and combines standard pacing lead insertion skills with techniques common to diagnostic cardiac catheterization and interventional cardiology. Integrating knowledge of cardiac anatomy with an understanding of the variety of available diagnostic cardiac catheterization tools, and familiarity with maneuvers used to advance catheters over guide-wires, allows the implanter to safely and effectively provide CRT for patients with CHF and conduction system disease. Data from more than 2000 patients enrolled in clinical trials of CRT suggest that the implantation technique is safe and effective; the success of LV lead implantation for CRT approaches 90%. Coronary sinus trauma occurs rarely and has little if any clinical sequelae. The rate of expected lead-related complications during the first year that require reoperation approaches 10%, and 30-day mortality associated with CRT device implantation is less than 1.5%.[10]

Pre-Discharge Patient Management

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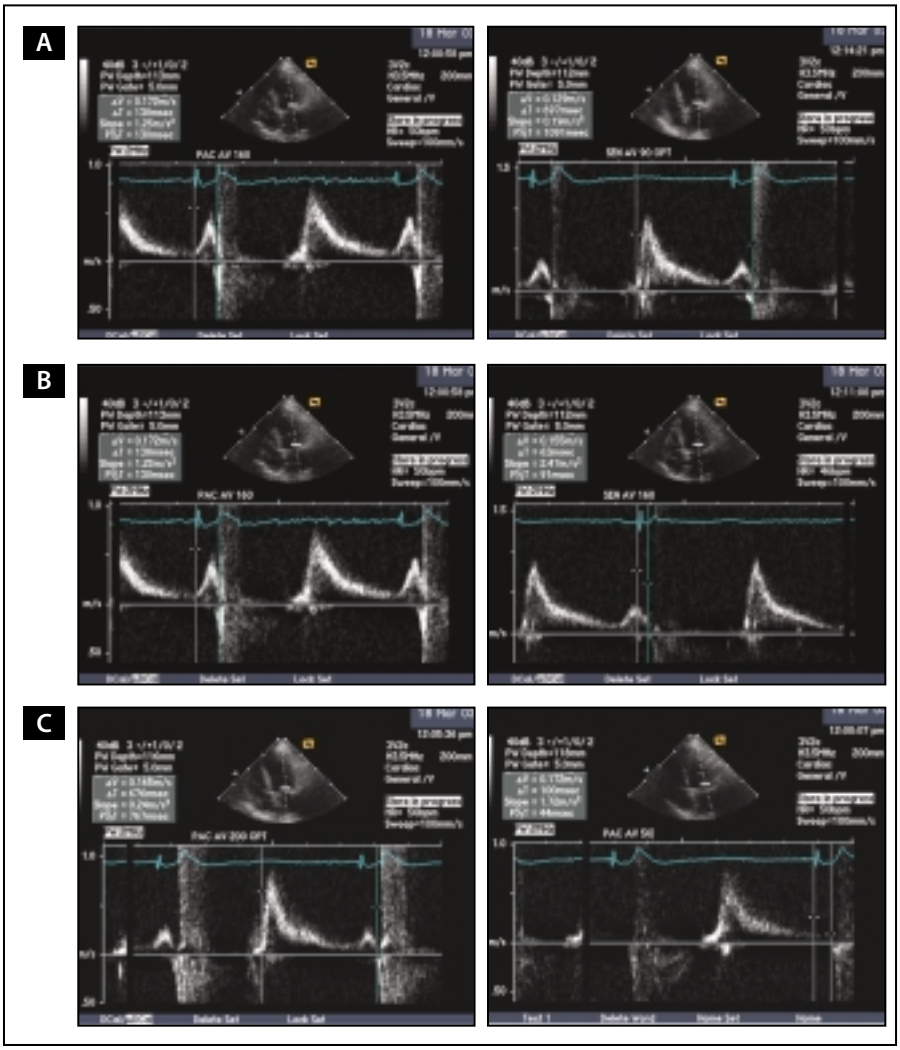

Figure 1. *Two-dimensional echocardiography assisted by continuous-wave Doppler interrogation of the mitral annulus measure flow across the valve during a sequence of programmed atrioventricular delay (AVD) settings in the same patient. The ideal configuration for the mitral Doppler envelope demonstrates separation between the E and A waves, with maximization of the area contained below the envelope. The optimal AVD separates the E and A waves (optimizing active atrial filling) while maximizing the area under the envelope (mitral flow).* **(A)** *The optimal AVD during atrial sensing usually differs from the optimal AVD during right atrial pacing due to the intrinsic delay between right atrial pacing and left atrial contraction (90 ms during atrial sensing vs 160 ms during atrial pacing).* **(B)** *Setting the same AVD for atrial sensing (left panel) and atrial pacing (right panel) produces markedly different Doppler filling patterns that may not optimize cardiac function.* **(C)** *Excessively long or excessively short AVDs markedly impair the mitral filling pattern.*

CRT patient involves the continuation of medical therapy, progressive ambulation, reinitiation of anticoagulation therapy (when indicated), and programming of the CRT device to achieve optimal cardiac function. Echocardiography assists in identifying optimal atrioventricular timing and helps set the optimal sequence and offset of right ventricular (RV) and LV pacing in newly available devices. Optimization of atrioventricular timing involves programming an atrioventricular interval that maximizes flow across the mitral annulus. Doppler echocardiography records mitral flow during various atrioventricular intervals and identifies the setting that maximizes the area of the flow envelope and optimizes the left atrial contribution to LV filling (Figure 1A). Proper optimization of the atrioventricular delay identifies the optimal atrioventricular delay during atrial sensing, as well as during atrial pacing. Intra-atrial conduction abnormalities produce latency and a delay between right atrial pacing and left atrial contraction. Failure to account for this delay may produce simultaneous left atrial and ventricular contraction during an excessively short programmed atrioventricular delay (Figures 1B and 1C). Typically, pre-discharge optimization is performed following the implantation and the patient is observed overnight and discharged on the first postoperative day. Predischarge testing should also include a 12-lead ECG demonstrating the biventricular capture morphology followed by the loss of LV capture, to serve as a template comparison of morphologies during follow-up (Figure 2A). A baseline chest radiograph in two views chronicles the initial lead position for comparison with future x-rays.

Early Post-Implant Care and Potential Adverse Events

Management of the CRT patient during the first month following implantation should focus on determining the degree of response to the therapy, the need to adjust any medications, and the detection of any device-related complications that may arise. Proper patient selection should increase the likelihood of achieving a positive response to CRT. Many patients detect an improvement in symptoms as early as 1 week after implantation. The most commonly reported changes in symptoms include less dyspnea, more energy, and a capacity for greater physical activity. A large proportion of responders to CRT devel-

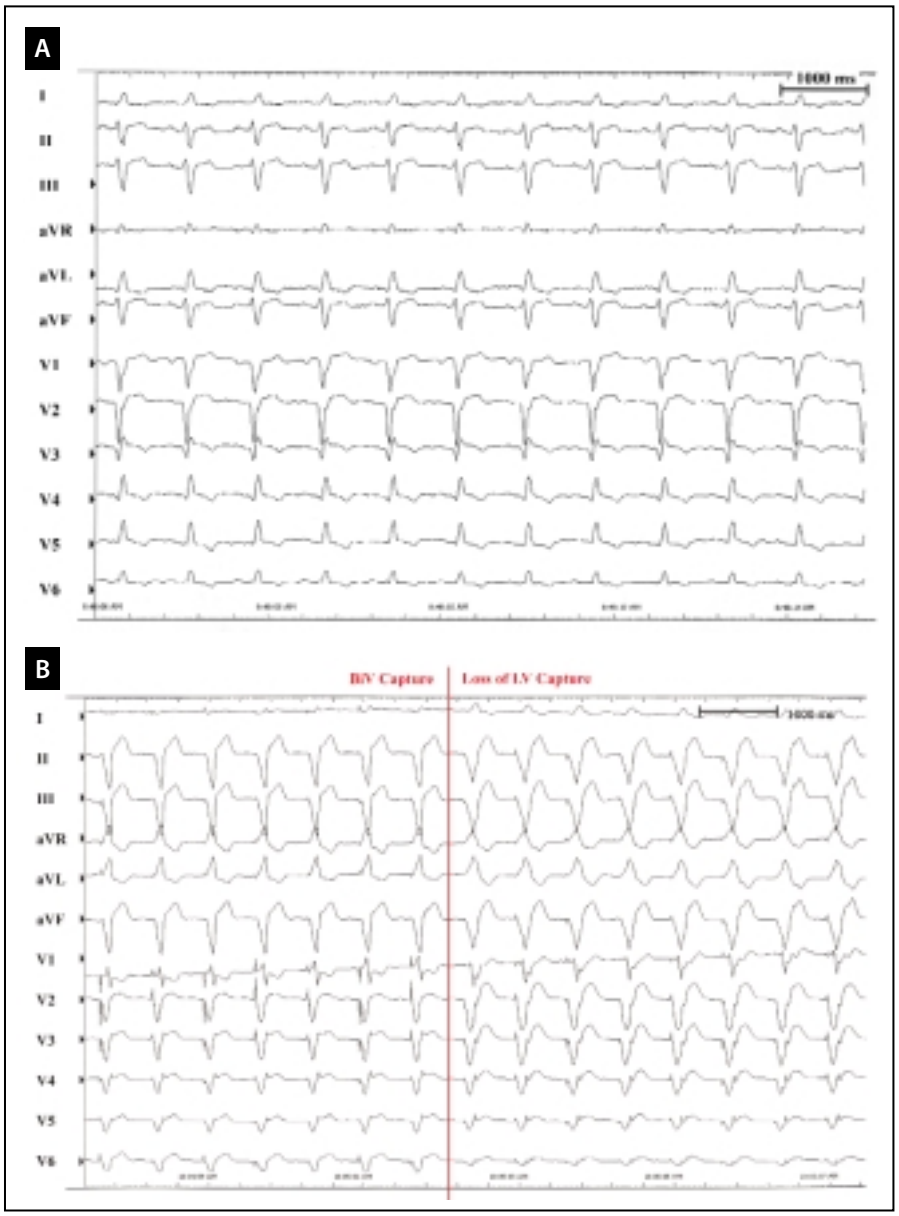

Figure 2. *The 12-lead electrocardiograph (ECG) best demonstrates the morphologic changes observed during biventricular pacing and during the loss of left ventricular (LV) capture and reversion to right ventricular capture only.* **(A)** *The baseline ECG in a patient with ventricular dyssynchrony often demonstrates a complicated left bundle branch block, with a QRS duration exceeding 130 ms. Left axis deviation/left anterior fascicular block denotes diffuse conduction system disease. LV capture changes the initial 40 ms of force to a rightward and anterior direction.* **(B)** *Loss of LV capture appears as a return to a leftward and posterior directed initial vector. The morphologic changes associated with loss of LV capture appear most obvious in ECG leads I and V1. Recording a 12-lead ECG template at implantation serves as a basis for future comparison to determine whether lead dislodgement or exit block have resulted in a loss of LV capture.*

op volume depletion and symptoms of orthostatic hypotension within 1 week after initiating CRT. Volume depletion results from an improvement of cardiac output and renal blood flow that promotes diuresis or from an effect on natriuretic peptides as cardiac function and filling pressures improve. Recognizing the development of volume depletion by finding orthostatic blood pressure changes should prompt a reduction in diuretic doses for these patients.

Adverse Events

The adverse events reported early after CRT device implantation typify complications associated with pacing systems and ICDs, with the additional risk inherent to LV lead implantation, extracardiac stimulation, and an increased LV lead dislodgement rate. Expected adverse events and complications after implantation include hematomata or bleeding, infection, pain, arm edema due to venous occlusion, and potential device-related complications, such as pacemaker-mediated tachycardia and ICD shocks. Most incision or pocket-related complications resolve with local care and use of analgesics. Large hematomata that impinge on neurovascular supply or continue to grow should prompt surgical drainage and exploration.

The development of infection, manifested by purulent drainage, or systemic signs, such as fever, bacteremia, or cellulitis, requires removal of the entire CRT system. Appropriate antibiotic therapy to eliminate the infection allows for another implantation attempt, usually using the uninvolved shoulder as the access site. Antibiotic therapy without device removal rarely appropriately treats infected implanted pacing/ICD systems. A transient benefit with antibiotic use usually results in worsened infection that is more difficult to treat.

The development of ipsilateral arm edema suggests that insertion of multiple leads into the subclavian vein has impaired venous return from the arm. If ultrasonography demonstrates venous thrombosis, initiation of intravenous heparin, followed by warfarin anticoagulation for 3 months, usually relieves

the edema and encourages the development of venous collaterals around the site of obstruction. The development of subclavian vein thrombosis rarely requires removal of the leads.

If a patient with a CRT device reports extracardiac stimulation, analysis of the pacing function of the CRT device should determine the LV pacing threshold and the diaphragmatic pacing threshold to determine whether programming changes can resolve the problem. LV pacing produces diaphragmatic contraction via stimulation of the phrenic nerve or by pacing the diaphragm directly. Rarely, LV leads can directly stimulate intercostal and chest wall muscles. Extracardiac stimulation occurs as a result of even minimal lead migration or a change in the relative position of the heart within the chest after the patient assumes a standing posture.

Lead dislodgement may also produce loss of LV capture and, therefore, loss of cardiac resynchronization. If the patient reports a worsening of symptoms and a return to preimplantation functional status after an interlude of improvement, loss of LV capture should be considered as a potential cause. If lead migration is suspected as the cause of extracardiac stimulation or loss of LV capture, a chest radiograph can help determine if the lead has migrated or dislodged. The surface electrocardiogram can determine whether pacing stimuli capture the right and left ventricles. Accurate differentiation of right ventricular, biventricular, and left ventricular capture often necessitates the use of multi-lead electrocardiography. Inspection of lead I best differentiates capture; V1 and the inferior leads provide supportive evidence (Figure 2B). Ideally, capture should be confirmed by observing morphologic changes in the 12-lead ECG as the amplitude of the pacing stimulus is changed. Availability of predischarge capture templates allows for accurate comparisons. If reprogramming the device output fails to resolve extracardiac stimulation or loss of LV capture, the patient should undergo revision of the LV lead to restore proper device function. Lead dislodgement may occur up to 1 year after device implant; therefore, the physician must remain vigilant to recognize potential effects of lead dislodgement, identify the problem, and refer the patient for device reprogramming or lead revision.

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Long-Term Management of the CRT Patient

Long-term follow-up of the CRT patient consists of regular visits to the PCP/cardiologist and heart failure specialist, echocardiography, device interrogation to obtain diagnostic/prognostic data, and maintaining device programming at optimal settings. The role of the electrophysiologist/implanting physician depends on the findings from device interrogation. Patient history and physical examination remain the cornerstone of determining clinical response to CRT. Echocardiography and cardiopulmonary exercise testing provide supporting evidence on the efficacy of therapy. Use of echocardiography to determine optimal device settings at regular intervals may improve the efficacy of CRT. The presence of atrial conduction abnormalities results in different optimal atrioventricular intervals during atrial sensing and atrial pacing. Echocardiographically guided device optimization may have greater importance in patients with questionable benefit after implantation. Dynamic changes in ventricular function associated with reversed remodeling during CRT may affect optimal settings over time.[11] Unscheduled visits for decompensated CHF should encourage a complete diagnostic evaluation to determine whether events are the result of progressive LV dysfunction, ischemia, noncompliance with medications, device malfunction, or noncardiac factors.

Use of echocardiography to determine optimal device settings at regular intervals may improve the efficacy of CRT.

Interrogation of diagnostic data recorded by the CRT device may provide insight into the risk of sudden cardiac death in patients with LV dysfunction, the long-term efficacy of the therapy, and the development of concurrent disease, such as cardiac arrhythmia or sinus node dysfunction. Device counters may record the presence of nonsustained or frequent ventricular tachycardia in patients with devices lacking ICD support. Such data may prompt upgrade to a CRT-ICD device to prevent sudden cardiac death. Changes in heart rate variability or resting

heart rate may reflect an improvement in ventricular function affecting parasympathetic tone. Failure to increase the atrial rate with a predominance of atrial pacing at the programmed lower rate suggests chronotropic incompetence and a progression of sinus node dysfunction that can be treated by changing the pacing mode. Recurrent atrial fibrillation or flutter may indicate the need for long-term anticoagulation. Devices that record intracardiac pressures and telemeter hemodynamic data to a central station are in development as a way to more effectively manage the CHF patient.

Proposed Management Strategy

At Emory Crawford Long Hospital, our strategy of care for CRT patients begins with a scheduled clinic visit 7 to 10 days post-implantation to check the wound and remove the sutures. The patient may report symptoms of volume depletion associated with post-CRT diuresis. Patients then return to the clinic at 3-month intervals. Routine patient surveillance includes a history taking, physical examination, device interrogation and, in patients with a questionable response to CRT, echocardiography to determine optimal device programming. Patients return to a facility that combines a standard pacemaker/ICD clinic with a center for heart failure therapy. This multidisciplinary approach combines clinical patient follow-up, education, lifestyle modification, optimization of pharmacologic and device therapy, and echocardiographic evaluation of ventricular function.

Improvements in systolic blood pressure may allow better tolerance of afterload reduction agents and, as previously indicated, CRT may also reduce the patient's diuretic requirement. Successful CRT does not eliminate the need for β-blocker or ACE inhibitor/ARB therapy. Heart rate support from CRT devices allows the physician to increase the dosage of β-blockers in patients with CHF. Patient education helps modulate volume and salt intake and emphasizes the recognition of signs of mild decompensation before the development of manifest CHF.

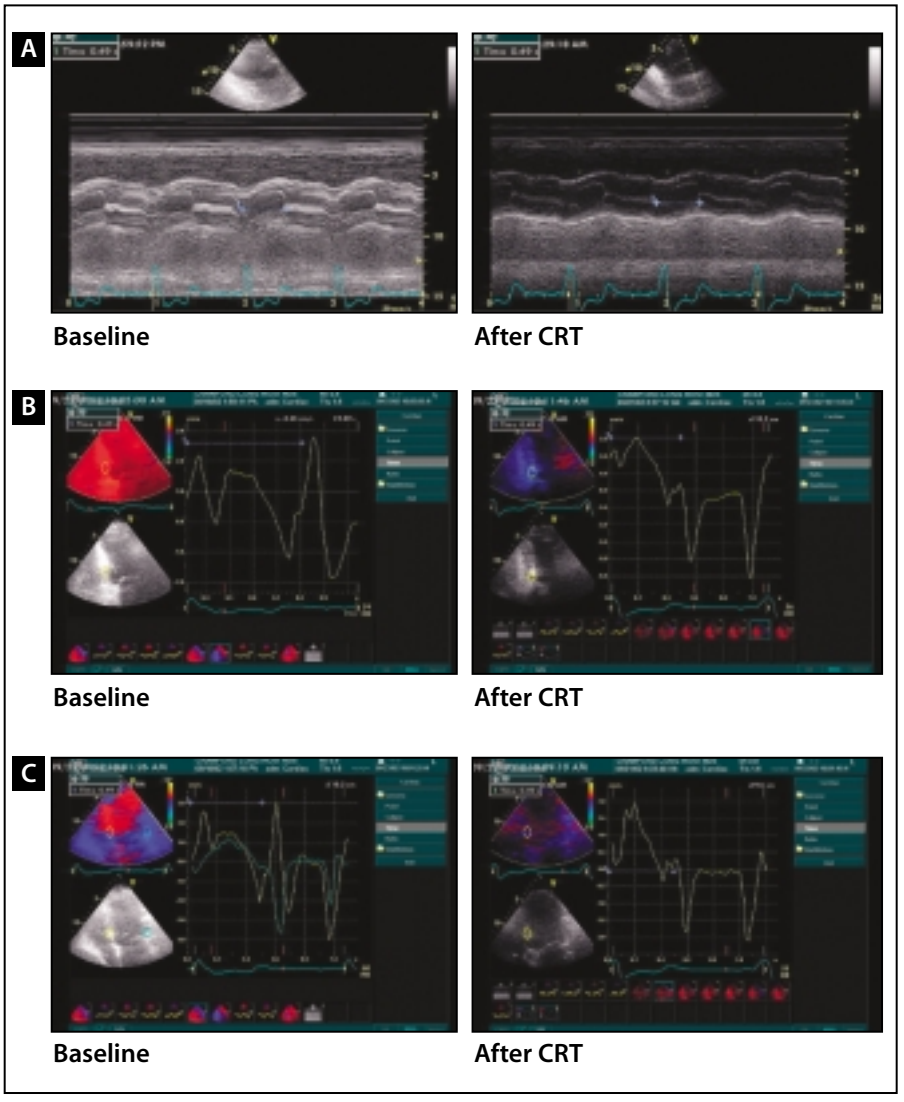

Figure 3. *M-mode echocardiography demonstrates a delay in the opening of the aortic valve in a patient with cardiac dyssynchrony.* **(A)** *The aortic pre-ejection interval shortens after successful resynchronization, reflecting more effective left ventricular (LV) contraction during biventricular pacing.* **(B)** *Tissue Doppler imaging at one segment in the inferior septum demonstrates post-systolic contraction as an upward deflection after closing of the aortic valve. (The red line denotes closure of the aortic valve.) Resynchronization of LV contraction eliminates most of the post-systolic motion.* **(C)** *Tissue Doppler imaging allows simultaneous detection of post-systolic motion at numerous segments prior to and after resynchronization.*

The programmed device parameters that require specific attention during follow-up include pacing mode; pacing sensor settings in patients with sinus node dysfunction; atrioventricular pacing interval; capture thresholds in the right atrium and right and left ventricles; and, when relevant, the right ventricle to left ventricle offset. Diagnostic

information obtained from the implanted device includes the presence of atrial and ventricular arrhythmias (used to guide antiarrhythmic therapy or consider upgrade to CRT-ICD), baseline heart rate, heart rate variability, and evaluation of battery service life.

Echocardiographic parameters of interest include overall LVEF, the presence and quantification of mitral regurgitation and, most recently, tissue Doppler imaging to quantify the degree of asynchrony before and after CRT. Cardiac imaging may not only serve as a useful tool for selecting optimal candidates for CRT but also help define response and refine device programming. Conventional parameters include the aortic preejection interval, which is the delay in aortic valve opening on M-mode after the inscribed QRS complex (Figure 3A). Novel methods using tissue Doppler imaging include measurement of post-systolic motion in various cardiac segments and measurement of the delay to peak contraction in the same segments before and after CRT (Figures 3B and 3C). Tissue Doppler imaging can quantitate the degree of baseline dyssynchrony, detect response to therapy, and guide optimal programming to reverse baseline abnormalities. Ongoing clinical evaluation will determine the role of imaging, specifically tissue Doppler imaging, in the management of the CRT patient.

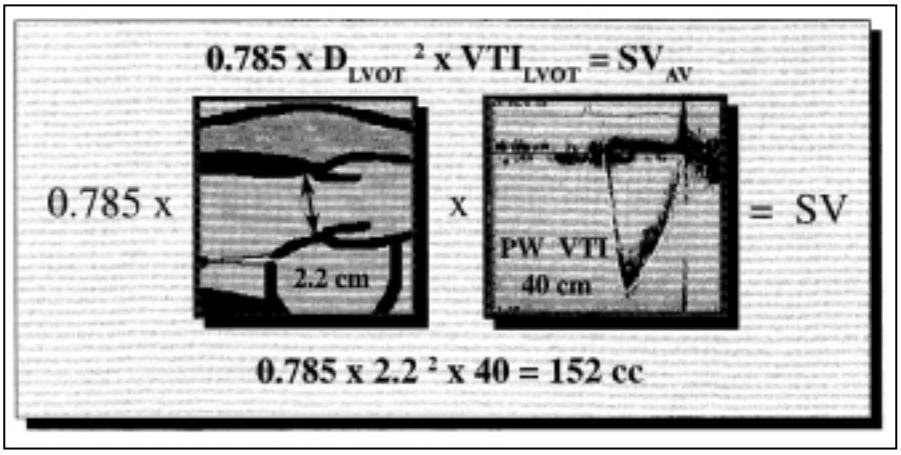

Figure 4. *The velocity time integral (VTI) method to estimate ventricular stroke volume uses two-dimensional echocardiography to measure the diameter of the left ventricular (LV) outflow tract and Doppler interrogation of the aortic interval to determine the stroke distance. Measuring the diameter of the LV outflow allows calculation of its cross-sectional area by assuming it is circular. The product of the cross-sectional area and the stroke distance (the distance to the outer edge of the aortic outflow envelope) estimates stroke volume (SV).*

Cardiac imaging may not only serve as a useful tool for selecting optimal candidates for CRT but also help define response and refine device programming.

Alternative Management Strategies

In numerous clinical trials, the benefit of CRT has been supported by evidence from cardiopulmonary exercise (CPX) testing, which demonstrates improvement in oxygen consumption during treadmill exercise (1.1–1.8 mL/kg/min).[1,12] Whether CPX testing provides any relevant clinical data beyond those obtained during routine clinical evaluation remains undetermined. Routine use of CPX testing generates expense, patient discomfort, and may have little impact on changing pharmacologic or device therapy in patients receiving CRT.

Impedance plethysmography to determine changes in aortic capacitance that reflect the effects of CRT on stroke volume has not demonstrated consistent results; inter-operator variability makes this method unreliable for widespread use in guiding CRT device programming. Whether plethysmography provides sufficient advantage over routine clinical evaluation to warrant the increased expense has not been proved.

Clinical evaluation of the InSync III cardiac resynchronization system incorporated Doppler estimation of LV stroke volume utilizing the velocity time integral (VTI) method to guide device programming. The VTI method measures the diameter of the LV outflow tract seen in two-dimensional echocardiography and calculates its cross-sectional area. Multiplying the cross-sectional area by the distance of the Doppler flow envelope in the outflow tract approximates ventricular stroke volume (Figure 4). The VTI method has been used to demonstrate a modest improvement in stroke volume during optimization of RV to LV offset.[13] However, technical complexity, large inter-operator variability, and the inconsistency of measurement within the respiratory cycle of any given patient diminish the practicality of the VTI method as a widely implemented tool for CRT patient follow-up.

Summary

A growing body of evidence supports the use of CRT in patients with LV

dysfunction and CHF. Wide implementation of CRT will create a population of patients with device therapy that requires PCPs and cardiologists to increase their knowledge of device-related effects, potential complications, and specific follow-up strategies to optimize the therapeutic benefit for each patient. A successful approach to patient management involves interaction among the PCP/cardiologist, the CHF specialist, and the cardiac electrophysiologist who monitors the effect of the therapy; modification of pharmacologic therapy; and management of device therapy. Regular clinical follow-up, with judicious use of echocardiography and device programming, optimizes CRT and will improve symptoms, quality of life, and functional capacity for patients with CHF. ■

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Main Points

- Proper management of the cardiac resynchronization therapy (CRT) patient involves an interaction between the primary care physician (PCP), cardiologist, electrophysiologist, and heart failure specialist.
- Optimization of atrioventricular timing involves programming an atrioventricular interval that maximizes flow across the mitral annulus. Doppler echocardiography records mitral flow during various atrioventricular intervals and identifies the setting that maximizes the area of the flow envelope and optimizes the left atrial contribution to left ventricular (LV) filling.
- Long-term follow-up of the CRT patient consists of regular visits to the PCP/cardiologist and heart failure specialist, echocardiography, device interrogation to obtain diagnostic/prognostic data, and maintaining device programming at optimal settings.
- Interrogation of diagnostic data recorded by the CRT device may provide insight into the risk of sudden cardiac death in patients with LV dysfunction, the long-term efficacy of the therapy, and the development of concurrent disease, such as cardiac arrhythmia or sinus node dysfunction.
- The programmed device parameters that require specific attention during follow-up include pacing mode; pacing sensor settings in patients with sinus node dysfunction; atrioventricular pacing interval; capture thresholds in the right atrium and right and left ventricles; and, when relevant, the right ventricle to left ventricle offset.
- Tissue Doppler imaging can quantitate the degree of baseline dyssynchrony, detect response to therapy, and guide optimal programming to reverse baseline abnormalities.