Heart failure (HF) is a syndrome that arises as a result of numerous cardiovascular disease processes. It affects 5.7 million Americans, with those older than 40 years having a 20% lifetime risk of developing HF. In 2008, it was estimated that more than $33 billion was spent on direct and indirect costs of treating HF.

Heart failure is more prevalent in the elderly population, with the growth of this cohort expected to expand from 35 million in 2010 to 70.3 million in 2030, increasing the incidence and prevalence of HF. Heart failure is more prevalent in the elderly population, with the growth of this cohort expected to expand from 35 million in 2010 to 70.3 million in 2030, increasing the incidence and prevalence of HF.

Heart failure has generally been described as a decline in cardiac contractility and left ventricular ejection fraction (LVEF), but HF can also occur in patients with a preserved LVEF. The definition of a patient with HF with a reduced LVEF (HFrEF) is measurement less than 40%. Heart failure with a preserved LVEF (HFpEF) is defined as HF with an LVEF of greater than 40%, and as a group is growing faster than the HFrEF population.

Treatment of Heart Failure
Heart failure is a progressive disease. Knowing functional classification and stages of HF development contributes to the understanding of medical and surgical management. These 2

ABSTRACT
The incidence of heart failure (HF) continues to increase, affecting millions of people in the United States each year. Cardiac resynchronization therapy (CRT) has been used and studied for patients with symptomatic HF for more than 20 years. The purpose of this article is to review technologies and developments to help maximize CRT for patients with symptomatic HF. Although most interventions to optimize CRT are physician directed, nurses also have an important role in the care and education of patients with symptomatic HF and can affect clinical outcomes. Therefore, nurses’ understanding of CRT and measures to maximize this life-saving therapy is critical in HF management. Key words: biventricular pacing, cardiac resynchronization therapy, heart failure
criteria complement each other in guiding treatment plans. The New York Heart Association (NYHA) functional classification indicates the degree of symptom burden, whereas the American College of Cardiology Foundation (ACCF)/American Heart Association (AHA) stages of development take into consideration the risk factors and cardiac structure abnormalities associated with HF. The ACCF/AHA stages are progressive and once a patient moves to a higher stage, regression is not observed. The NYHA classification has been described extensively in the literature and refers to the degree of HF symptoms with normal activity levels. The NYHA classes range from I to IV. Class I patients are essentially asymptomatic with normal activity, whereas class IV patients experience symptoms at rest. The stages of HF development start with normal function at stage A and progress to stage D, comprised of patients with HF symptoms refractory to specialized interventions.

The cornerstone of medical therapy for patients with HF includes β-blockers, angiotensin-converting enzyme (ACE) inhibitors or angiotensin-receptor blockers (ARBs), and aldosterone antagonists. The latest 2013 ACCF/AHA HF guidelines delineate the indications and target doses of each medication as tolerated and facilitates multiple aspects of guideline-directed medical therapy (GDMT). The guidelines provide initiation and maintenance recommendations for pharmacological agents to treat each stage and functional class of HF as well as for specific conditions and populations. The guidelines also address multiple lifestyle modifications including but not limited to dietary recommendations, weight loss, sleep disorder, exercise, and control of risk factors and conditions that can lead to HF. Current recommendations for placement of implantable cardioverter defibrillators (ICDs) are indicated after optimization of GDMT for at least 3 months for patients with an LVEF of 35% or less and who are more than 40 days after myocardial infarction in the HFpEF population. It is important to emphasize that cardiac resynchronization therapy (CRT) is indicated only after stable GDMT is achieved.

**CRT and HF**

Cardiac resynchronization therapy or biventricular pacing has become a recognized standard of care therapy for patients with symptomatic HF, depressed left ventricular (LV) function, and markers of ventricular dysynchrony despite optimized GDMT. Current guidelines use a QRS width of more than 120 ms as a marker of dyssynchrony. Ventricular dyssynchrony can result from interventricular (VV) and/or intraventricular delays. Interventricular dyssynchrony occurs when there is a delay between right ventricle (RV) and LV activation. Intraventricular dyssynchrony occurs when the normal ventricular activation sequence is disrupted and dis coordinated contraction of the LV segments occurs. Cardiac dyssynchrony can result in cardiac remodeling, which results in LV dilation, worsening of systolic and diastolic function, and progressive HF symptoms. Echocardiography with different modalities such as conventional 2-dimension/M-mode, tissue Doppler imaging, strain-rate imaging, and tissue tracking are available to monitor and evaluate dyssynchrony. Current guidelines for CRT include LVEF 35% or less, electrocardiographic QRS duration of more than 120 ms, and symptoms of HF consistent with NYHA classes II to III despite optimal medical therapy.

Biventricular pacemakers have become apparent over the years as a way to restore synchronous left and right ventricular contraction. The addition of the LV lead was initially implanted surgically, but the coronary sinus (CS) route was demonstrated to be safe and efficacious and now has become the standard mode of implantation. Over the past 20 years, technology and skills have improved tremendously and CRT has been shown to improve the symptoms of HF and quality of life (QOL) in patients who are not controlled with GDMT alone. Resynchronization of the ventricles leads to improved mechanical pumping efficiency and multiple studies have shown reductions in LV volume, and improved LVEF that often translates into reports of improved functional capacity and perceived improvement in QOL and survival benefits.

**Evolution and Clinical Benefits of CRT/Core Trials**

The initial CRT landmark trials were conducted on patients with NYHA classes III-IV HF symptoms. These landmark trials, including the Multi-site Stimulation in Cardiomyopathy (MUSTIC), Multicenter InSync Randomized Clinical Evaluation (MIRACLE), Cardiac Resynchronization on Mortality and Morbidity in Heart Failure (CARE HF), and Comparison of Medical
Therapy, Pacing and Defibrillation in HF (COMPANION) trials, showed improvement in symptoms and QOL and 6-minute walk distance and reduction in LV volumes and HF hospitalizations (Table 1). The COMPANION study was the first trial to demonstrate a mortality benefit as a result of CRT-defibrillator (CRT-D) therapy, whereas the CARE-HF trial demonstrated mortality improvement with CRT-pacing (CRT-P) alone.21

As the benefits of CRT emerged, subsequent clinical trials extended criteria to include patients with mild to moderate symptomatic HF. These studies include Cardiac Resynchronization Therapy for the Treatment of Heart Failure Patients with Intraventricular Conduction Delay and Malignant Ventricular Tachycardia (CONTAK-CD),23 MIRACLE (ICD-II) Trial,24 Multicenter Automatic Defibrillator Implantation with Cardiac Resynchronization Therapy (MADIT-CRT),25 Resynchronization-Defibrillation for Ambulatory Heart Failure (RAFT),26 and the ReSyncronization reVerse Redmodeling in Systolic Left vEntricular dysfunction (REVERSE)27 trials. These studies showed improvement in LVEF and LV dimensions and reduction in HF hospitalization.21–27

The earlier CRT trials enrolled patients with NYHA classes III to IV, more severe symptoms of HF, and longer QRS duration. More recent studies have expanded their inclusion criteria to those with fewer symptoms and shorter QRS durations, focusing on earlier intervention in the disease progression continuum. The benefits of improvement in functional class, QOL, and LVEF have been demonstrated with multiple studies over the years. Therefore, CRT has become an established therapy in the HFrEF patient population.

Current Guidelines for CRT
Heart failure clinical guidelines recommend a course of GDMT with β-blockers, ACE inhibitors or ARBs, and aldosterone antagonists before initiating device therapy.2 Criteria defined in current guidelines for CRT are for symptomatic HF despite GDMT with depressed LVEF of 35% or less, and electrocardiographic QRS of 120 ms or more. Since 2010, CRT guidelines have expanded to include patients with mild symptoms such as those in NYHA class II. In the 2012 updated guidelines, class I recommendations for CRT use were established for patients with reduced LVEF, left bundle branch block (LBBB), and a QRS of 150 ms or more. QRS duration of 120 to 149 ms remains a class IIA recommendation.11,13

Nonresponders and Efforts to Maximize CRT
To date, there is no standard definition of response to CRT, and considerable variability in defining patient response exists in clinical practice. However, widely accepted measures for response failure 6 months after implant can be divided into 2 main categories: clinical end points indicating no improvement in clinical status (NYHA functional class, QOL scores, exercise capacity expressed in 6-minute walk distance) and echocardiographic end points indicating no improvement in LV systolic function, reversed LV remodeling, or LV volumes. Approximately one third of patients are labeled as nonresponders.20,28–30 The actual rate may be as high as 40% to 50%, because nonresponders may have been underrepresented in studies.31 With a significant percentage of patients not responding to CRT, there have been tremendous efforts to optimize or maximize CRT. The focus of many efforts has been around lead placement, maximizing the percentage of biventricular pacing, optimizing device programming, postimplant clinical optimization, and appropriate patient selection.

LV Lead Placement
A central vein (subclavian, cephalic, or axillary) is accessed via a percutaneous approach. The right atrial lead is placed in the right atrial appendage. The RV lead is usually placed in the apex or mid-septum of the RV. The LV lead is advanced through the CS into one of the venous side branches along the left lateral or posterolateral wall of the left ventricle.

One of the primary therapeutic goals of CRT is the restoration of coordinated ventricular contraction. The position or placement of the LV lead contributes to this resynchronization. The lateral or posterolateral branch of the CS is the current preferred LV lead placement site. The lateral free wall LV placement site demonstrated the greatest degree of improvement in measured contractility as first demonstrated in 2001 as compared with anterior sites. Placement of the LV lead in the apical position was found to be suboptimal resulting in increased HF events and mortality in the MADIT-CRT trial.12,33
<table>
<thead>
<tr>
<th>Trials</th>
<th>No. of Subjects</th>
<th>Inclusion Criteria</th>
<th>Design</th>
<th>Major Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUSTIC</td>
<td>58</td>
<td>NYHA class III</td>
<td>Single-blinded, crossover, OMT vs OMT + CRT</td>
<td>CRT-P improved 6MWD, NYHA class, QOL, peak $\dot{V}O_2$, reduced LV volume and hospitalizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 150 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEDD $&gt; 60$ mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIRACLE</td>
<td>453</td>
<td>NYHA classes III-IV</td>
<td>Double-blinded, randomized, CRT vs OMT</td>
<td>CRT-P improved NYHA class, QOL, 6MWD, and LVEF Reduced LVEDD, MR, and HF hospitalizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 130 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEDD $&gt; 55$ mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARE-HF</td>
<td>813</td>
<td>NYHA classes III-IV</td>
<td>Double-blinded, randomized, OMT vs CRT</td>
<td>CRT-P decreased HF hospitalizations and mortality Improved QOL, LV reverse remodeling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 120 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPANION</td>
<td>1520</td>
<td>NYHA classes III-IV</td>
<td>Double-blinded, randomized, CRT-P vs OMT + CRT-D</td>
<td>CRT-P and CRT-D decreased all-cause mortality and HF hospitalizations, CRT-D improved mortality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 120 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTAK-CD</td>
<td>490</td>
<td>NYHA classes II-IV</td>
<td>Double-blinded, randomized, CRT-D vs CRT-P</td>
<td>CRT-D improved LVEF, LV dimensions and 6MWD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 120 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIRACLE ICD-II</td>
<td>186</td>
<td>NYHA classes II-IV</td>
<td>Double-blinded, randomized, ICD vs CRT-D</td>
<td>CRT-D improved NYHA class, reduced LV volumes, and improved LVEF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 130 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MADIT-CRT</td>
<td>1820</td>
<td>NYHA classes I-II</td>
<td>Single-blinded, randomized, OMT + ICD vs CRT-D</td>
<td>CRT-D reduced LV volumes, HF related hospitalizations and mortality, and improved LVEF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 30%</td>
<td></td>
<td>Benefits more pronounced in subgroup with QRS $\geq$ 150 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 130 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RAFT</td>
<td>1798</td>
<td>NYHA classes II-III</td>
<td>Double-blinded, randomized, OMT + ICD vs CRT-D</td>
<td>CRT-D decreased HF events and mortality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 120 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REVERSE</td>
<td>610</td>
<td>NYHA classes II-III</td>
<td>Double-blinded, randomized, CRT-on vs CRT-off</td>
<td>CRT (P or D) reduced HF hospitalizations and improved LV reverse remodeling—reduction in LV volumes and improvement in LVEF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LVEF $\leq$ 40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>QRS $\geq$ 120 ms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CRT, cardiac resynchronization therapy; CRT-D, biventricular defibrillator; CRT-P, biventricular pacemaker; HF, heart failure; ICD, implantable cardioverter defibrillator; LV, left ventricular; LVEDD, left ventricular end-diastolic dimensions; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; OMT, optimal medical therapy; QOL, quality of life; MR, mitral regurgitation; 6MWD, 6-minute walk distance; $\dot{V}O_2$, volume of oxygen.
Placement by Electrical Measurement
Numerous methods are available to identify the ideal location for an LV lead placement. One such technique uses purely electrical measurements. The QLV is the measurement between the onset of the surface QRS and the beginning of the LV local electrogram. van Gelder et al\textsuperscript{34} have shown that targeting sites with greater QLV results in greater hemodynamic benefit. In the SMART-AV trial sub-study, Gold et al\textsuperscript{35} demonstrated improved reverse remodeling and QOL scores with a targeted approach using QLV. Using electrical measurements has the distinct advantage of being easily measured and reproducible.

Placement by Echocardiography Measurements
The use of echocardiographic measurements of dyssynchrony is another approach. Ansalone et al\textsuperscript{36} reported that tissue Doppler imaging-guided LV lead placement in the area of latest segment of mechanical contraction resulted in superior clinical benefits. The Targeted Left Ventricular Lead Placement to Guide Cardiac Resynchronization (TARGET) study used speckle-tracking echocardiography to target LV lead placement at the latest site of peak contraction to signify freedom from scar. The results showed greater LV reverse remodeling, improved clinical response, and lower rates of combined death and HF-related hospitalization.\textsuperscript{37} The TARGET trial is the first randomized, controlled study to demonstrate the benefit of a targeted approach using echocardiography for LV lead placement in CRT. The Speckle Tracking Assisted Resynchronization Therapy for Electrode Region Trial (STARTER) also demonstrated improvement in ventricular dyssynchrony, with reduction of HF hospitalization or death with LV lead placement directed toward the site of latest mechanical activation and with avoidance of areas of scar in the speckle tracking echocardiography group.\textsuperscript{38}

Numerous single-center studies suggest the benefits of using echocardiographic parameters for determining mechanical dyssynchrony that may lead to improved patient selection for CRT. However, not all published studies are in agreement. The Predictors of Response to CRT (PROSPECT) Trial, a multicenter trial involving 53 centers, did not find a single echocardiographic measure of dyssynchrony to improve patient selection for CRT beyond current guidelines.\textsuperscript{39} Fornwalt et al\textsuperscript{40} reviewed 50 publications with the most citations, and after excluding editorials and review articles, they found and evaluated 17 different primary response criteria identified from 26 relevant articles. In those 26 publications on predicting response to CRT, agreement for methods to define response to CRT was “poor” 75\% of the time and “strong” only 4\% of the time. These findings severely limit the generalized results reported by multiple other studies.\textsuperscript{40} Moreover, the use of echocardiography requires a great deal of expertise that varies tremendously between laboratories and inter-observer variability remains a problem even within clinical trials.

Even with electrical or echocardiographic guidance, the intrinsic limitations of a transvenous approach still exist, being dependent on venous anatomy, the presence of epicardial fat or dense myocardial scar, and proximity to the phrenic nerve.\textsuperscript{29}

Myocardial Scar
Scar burden may be another determinant of response to CRT. A large myocardial scar burden assessed by either single-proton emission computed tomography imaging or magnetic resonance imaging is associated with poor response to CRT and an overall poor prognosis.\textsuperscript{41–43} The association between high scar burden and poor CRT may partially explain why nonischemic cardiomyopathy tends to respond better to CRT than ischemic cardiomyopathy. The location of the scar in relation to the LV lead has been an important factor in the success of CRT. A transmural scar in the posterolateral LV segments may result in clinical and echocardiographic nonresponse to CRT.\textsuperscript{44} A lead in a scar region is unlikely to pace the left ventricle effectively.

Suboptimal Biventricular Pacing
Maintaining a high percentage of biventricular pacing has been correlated to maximum CRT benefit. In a retrospective analysis of 1812 CRT patients, the greatest magnitude of benefit was observed in those with more than 92\% biventricular pacing.\textsuperscript{35} In another trial, data were analyzed from the large cohort of the ALTITUDE study participants. The relationship of biventricular pacing to HF symptoms and survival was evaluated in 36 935 patients who were being followed by a remote
monitoring system. In this population, a lower percentage of biventricular pacing was associated with worsening HF symptoms. Survival rate was significantly increased when biventricular pacing was more than 98.5%, leading the authors to recommend pacing as close to 100% of the time as possible.46 Hayes et al46 also found that older male patients were more likely to have reduced biventricular pacing because of inappropriate programming of long atrioventricular (AV) delays. Maximum biventricular pacing and its benefit have been shown to be diminished in patients with atrial arrhythmias, frequent premature ventricular beats, and programmed longer AV delays.47 Cheng et al47 performed a retrospective analysis, using a remote monitoring system database. They analyzed data for 80,768 patients with results showing 40.7% having less than 98% biventricular pacing primarily as a result of atrial tachycardia/atrial fibrillation (AF), premature ventricular beats, and ventricular sensed episodes.48

Reasons for Suboptimal Pacing
Normal functioning pacing devices will not pace above the programmed upper rate limit. In patients prone to tachycardia, pacing may be inhibited, thereby negating the potential benefits of CRT. For patients in AF with a rapid ventricular response, pharmacological therapy may be effective for rate or rhythm control. If medication therapy fails, then AF ablation or AV node ablation may be considered. In the largest observational study to date, Gasparini et al48 explored the outcome of CRT in combination with AV ablation or rate-slowering drugs in patients with permanent AF. Atrioventricular nodal ablation was found to reduce all cause and cardiovascular mortality rate.49-52 Yin et al50 also found that AV nodal ablation improved clinical response and significantly lowered nonresponse to CRT among patients who have less than 90% biventricular pacing prior to ablation. In addition to significant reduction in all cause and cardiovascular mortality rate, Ganesan et al51 also noted improvement in NYHA functional class in patients with AV node ablation and CRT when compared with the medical therapy group. The Cardiac Resynchronization Therapy in Atrial Fibrillation Patients Multinational Registry (CERTIFY study) found long-term survival after CRT among patients with AF and AV node ablation similar to that observed in patients in sinus rhythm. Mortality rate was found to be higher for the AF patients treated with rate-slowing drugs.51 However, the Pulmonary Vein Antrum Isolation versus AV Node Ablation with Bi-ventricular Pacing for Treatment of Atrial Fibrillation in Patients with Congestive Heart Failure (PABA-CHF) study53 was a multicenter, randomized controlled trial comparing pulmonary vein isolation with AV node ablation with biventricular pacing. Eighty-one patients were enrolled: 41 in the pulmonary vein isolation group and 40 in AV nodal ablation group. The pulmonary vein isolation group showed improvement in LVEF, 6-minute walk distance, and QOL compared with AV nodal ablation, suggesting a larger benefit from a rhythm control strategy.53 Large, prospective randomized trials evaluating AF ablation, AV node ablation with AF, and CRT are needed.

Additional Pacing Issues
High capture thresholds and phrenic nerve stimulation (PNS) are also issues with LV leads. They are often addressed with decreasing LV output below the recommended safety margin or programming the LV lead off, which contributes to the problem of suboptimal biventricular pacing. One study found that 37% of their CRT patients experienced PNS contributing to decreased percentage of CRT pacing.54 Multipolar LV pacing electrodes have been demonstrated to decrease the need for lead repositioning by providing more options for pacing.55

Optimizing Device Programming
Atrioventricular and VV timing factors in CRT have generated considerable interest for research. The goal of AV optimization is to time the atrial contraction during ventricular relaxation, thus improving ventricular filling. Echocardiography has been used to identify the AV delay yielding maximum LV filling and in assessing VV and intraventricular dysynchrony. The goal of the VV timing is to synchronize the right ventricular contraction with the LV contraction to minimize VV dysynchrony. However, the VV timing process is complex and time consuming, has not been shown to improve outcomes, and appears to be as effective as nominal device settings.56 Device companies have devised automated AV and/or VV timing optimization algorithms in an attempt to improve CRT effectiveness.
Although numerous small studies have shown short-term benefits of AV and VV timing optimization, benefits have not been shown in larger randomized trials. Ellenbogen et al found that neither device automated AV delay programs nor echocardiographic optimization was superior to a fixed AV delay of 120 ms. A recent meta-analysis of randomized and non-randomized studies showed that routine AV and/or VV delay optimization has a neutral effect on clinical and echocardiographic outcomes. However, in the nonresponder population, AV and VV optimization may provide some benefit. Mullens et al reported that 47% of patients referred to their CRT optimization clinic had devices that were suboptimally programmed. Their CRT optimization program took a multidisciplinary team approach. Each patient visit started with a comprehensive evaluation by the HF nurse followed by a designated cardiologist and then a device interrogation with echocardiographic assessment during different AV settings with and without biventricular pacing. Then the patient met with the multidisciplinary team comprised of an HF specialist, electrophysiologist, and cardiac imaging specialist. The team’s recommendations for this nonresponder population led to 88% of patients with improved echocardiographic indexes of LV filling and LV ejection when compared with a temporary VVI backup setting. This optimized setting of their CRT resulted in fewer adverse events.

Postimplant Clinical Management

It is vital that GDMT for HF is optimized before considering CRT. Evidence shows that suboptimal GDMT is linked with less improvement from CRT. The Registry to Improve the Use of Evidence-Based Heart Failure Therapies in the Outpatient Setting (IMPROVE HF) reviewed records of 15,381 patient receiving care at 167 outpatient cardiology practices. Patients in the IMPROVE HF trial who were treated with device therapy received ACE inhibitor or ARB therapy more often than those not treated with a device, but one third received less than the recommended target dose. The same was found with β-blockers, with only 20% of patients with ICD or CRT devices receiving the recommended target dose. Another group found that 32% of patients referred to their CRT optimization clinic had suboptimal medical therapy. Undertreating with medical therapy is not limited to North America; it has been seen in the treatment of HF in European and Mediterranean countries as well. These studies demonstrate the importance of medication optimization with CRT device therapy. Medical therapy treats symptoms and clinical effects of HF and improves control of the intrinsic heart rate, which may affect the percentage of CRT pacing.

Future Trends

Multisite Pacing

In an attempt to improve CRT response, alternate methods of CRT delivery are being explored. One example is multisite pacing, which is based on the hypothesis that pacing at multiple points within the ventricles will improve cardiac resynchronization. Triventricular pacing, with one RV lead and two LV leads, has been shown to be safe and effective in improving clinical and echocardiographic endpoints over biventricular pacing. Although effective, triventricular pacing has a higher rate of complications including excessive fluoroscopy time during implant, and lead-related complications such as infection, vein thrombosis, damage to leads, and lead dislocation. Promising newer technology, such as multipolar LV leads, has the ability to deliver multisite pacing through a single CS lead. Initial trials show improvement in hemodynamic response with less dyssynchrony.

Although PNS and high LV capture thresholds represent an important limitation to the delivery of CRT with standard leads, other advances such as “electronic repositioning” may overcome these issues by selecting different pacing vectors and/or adjusting pacing output to ensure LV capture, thereby avoiding PNS with multisite pacing lead systems. Initial outcomes have been positive and current trials are still in progress.

Leadless Pacing

The introduction of leadless pacing capability provides the potential for targeting LV endocardial pacing sites. The Wireless Stimulation Endocardially for CRT (WiSE-CRT) is evaluating the safety and feasibility in eligible HF patients for CRT. Potential advantages of implanted leadless LV pacing include lower capture thresholds, reduced PNS, stability of an active fixation endocardial receiver electrode, site of LV stimulation, reduced arrhythmogenia, and improved ventricular
resynchronization. It also gives less concern about lead-related complications such as infections or fractures.\textsuperscript{72,73} With ongoing studies, more information and data are expected in the near future.

**Patient Selection**

Most of the data in randomized clinical trials evaluating the effectiveness of CRT in HF have been acquired from patients with LBBB. Patients with right bundle branch block or interventricular conduction delay were not as well represented in these test populations.\textsuperscript{41} The MADIT-CRT trial showed no clinical mortality or HF episode benefit to patients with non-LBBB pattern, such as right bundle branch block or interventricular conduction delay.\textsuperscript{74} The most recent North American guidelines have limited class I recommendations for CRT to patients with LBBB and QRS duration of 150 ms or greater.\textsuperscript{7} Identification of potential nonresponders preimplant and close monitoring of CRT patients may improve its effectiveness. Trials are currently ongoing to assess strategies in the non-LBBB population.

**Home Remote Monitoring**

Home remote monitoring with cardiac implanted electronic devices for early detection of fluid overload helps in early detection of HF exacerbation, thereby decreasing HF hospitalizations.\textsuperscript{75,76} Thoracic impedance monitoring with cardiac implanted electronic devices measures a drop in electrical impedance (ohms) across the thoracic cavity reflecting an increase in pulmonary vascular congestion.\textsuperscript{76,77} A study by Yu et al.\textsuperscript{77} noted decrements in impedance 15 days prior to worsening HF symptoms and demonstrated a strong correlation to a change in pulmonary capillary wedge pressure in a subset of patients. The Fluid Accumulation Status (Fast Trial) found the sensitivity and unexplained detection rate of intrathoracic impedance monitoring superior to weight changes for detecting HF.\textsuperscript{75} The SENSE-HF Trial found that intrathoracic impedance index had low sensitivity and positive predictive value in the early postimplant period but sensitivity improved within the first 6 months after implant.\textsuperscript{80} Intrathoracic impedance monitoring is not available in all ICDs. Other useful information routinely transmitted through remote monitoring includes intrinsic activity, heart rate variability, detection of arrhythmias, ectopy burden, and percentage of pacing. All are useful information to monitor and maximize CRT for our HF patients. In the future, it is likely that direct pressure monitoring such as pulmonary arterial pressure or left atrial pressure will be used in conjunction with CRT devices.\textsuperscript{81,82}

**Implications for Nursing**

Research and evidence demonstrating the nursing role specific to maximizing CRT benefit are lacking. However, a multidisciplinary approach, including specialized nursing, has been demonstrated to improve HF outcomes and decrease hospitalizations.\textsuperscript{83} The bedside nurse is involved in monitoring the moment patients are admitted for worsening symptoms of HF to the time of their discharge. Nurses play a role in ongoing patient education about HF management and optimizing CRT by applying knowledge for closer monitoring of patient status and educating patients on managing their heart disease.

Advanced practice nurses specializing in cardiovascular care and nursing clinical educators play a major role in educating bedside nurses caring for these patients. As a result of the complexity of factors and conditions associated with symptomatic HF, nurses need an in-depth knowledge of the multiple components of HF pathophysiology and therapy including pharmacological treatment, lifestyle modification, rehabilitation, and resynchronization device therapy.

Nurses’ contribution to maximizing CRT for patients with symptomatic HF involves participating in continuing education on the basics of CRT, understanding the function of the currently available devices, and knowing indications for treatment and implantation-related complications. For example, strong electrocardiographic skills are essential in the ability to assess patients’ rhythms after implantation of biventricular devices. Proper functioning of CRT devices is manifested by appropriate pacemaker spikes within 3 cardiac chambers, the right atrium and both ventricles.\textsuperscript{85} Early identification of inappropriate pacing or loss of pacing capture troubleshoots inefficient device function in a timely manner. Identification of AF or other arrhythmias that lead to inconsistent biventricular pacing is critically important.

Other nursing responsibilities include coordinating patient care, properly assessing the patient’s condition, and recommending possible solutions as problems are identified.
Clinicians direct patient care with the appropriate assessment of patients’ medical conditions, symptoms, and functional level. Nurses provide education and reassurance to the patient and their family on an ongoing basis. Advanced practice nurses contribute to the recognition of potential CRT device complications such as PNS pacemaker failure, pneumothorax, infection, cardiac tamponade, bleeding, and hematoma as well as monitoring for and correcting conditions that can lead to suboptimal pacing. The patients admitted for HF management with subsequent implantation of a CRT device need comprehensive and understandable explanations of their medical care. The overall goal of patient education is to promote patient involvement and self-care responsibilities. A multidisciplinary approach must start on the day of admission and continue until discharge. Educational materials should be clear and appropriate to the patient’s level of understanding. Patients admitted and receiving CRT therapy must understand the type of device they had implanted and the expectations associated with living with that device. Patients need to know who and when to call in the case of implantation-related complications such as local or systemic infection, pocket hematoma, bleeding, and pneumothorax. The importance of follow-up appointments needs to be emphasized prior to discharge and the use of home remote monitoring reviewed. An important educational piece for the patient is that CRT alone will not help manage their symptoms; therefore, they must follow all regimens prescribed for their care including prescribed medication administration, with special consideration for lifestyle and dietary modifications. Given that nurses play an integral role in the care of these symptomatic HF patients, they must understand the treatment for HF and optimizing CRT.

Conclusion
The challenge today is keeping up with trends and technologies involved in caring for the symptomatic HF patient population. Cardiac resynchronization therapy is a standard therapy, but given the number of patients who are nonresponders, the focus remains on improving this treatment strategy. Keeping abreast of the changing technology will be key for nurses to optimally care for CRT patients.

Acknowledgments
The authors gratefully acknowledge Fatmata Jalloh, NP, for her assistance with the background information in this article and Lynn Doering, RN, PhD, for her editorial contributions.

REFERENCES


