Heart failure is a debilitating chronic condition that affects more than 5 million patients in the United States. The condition is complex and incurable, but multiple medications, procedures, and devices are available to treat it. Biventricular pacing, a therapy for some patients with heart failure, can improve quality of life and reduce the number of hospitalizations and mortality. In this article, I discuss selection of patients and devices, the procedure used to implant the pacemaker, potential complications, and assessment of the function of biventricular pacemakers. Nurses who provide care for patients with permanent pacemakers and biventricular pacemakers should be knowledgeable in the assessment of electrocardiographic (ECG) findings related to adequate functioning of biventricular pacemakers. In addition, I provide bedside critical care or telemetry nurses the information to determine if a biventricular pacemaker is functioning and when to contact a cardiologist to determine if further interrogation of the pacemaker or correction of timing is needed.

Indications for Biventricular Pacing in Heart Failure

Multiple indications exist for implanting a biventricular pacemaker in patients with heart failure, and the indications are continuously being reevaluated to include a broader range of patients with the diagnosis of heart failure. According to the Heart Failure Society of America, biventricular pacing is recommended for patients with sinus rhythm, a widened QRS interval greater than 120 ms, and a left
ventricular ejection fraction (LVEF) of 35% or less.\(^4\) Approximately one-third of patients with systolic heart failure have left bundle branch block with a QRS duration greater than 120 ms.\(^{3,4,8}\) Indications noted by the American Heart Association for biventricular pacing include LVEF of 35% or less, left bundle branch block with QRS duration 150 ms or greater, and heart failure greater than class II according to the New York Heart Association classification\(^6,7\) (Table 1). These criteria are dynamic, and selection of the device to be used and the decision to implant a device may depend on a patient’s signs and symptoms and decreasing functional status and local insurance-related criteria for reimbursement. Patients with New York Heart Association level I or level II heart failure may be eligible for insertion of a biventricular pacemaker if the ejection fraction is less than 30% and the QRS interval is 130 ms or greater.\(^6,8\)

Biventricular pacing may also be considered for patients with atrial fibrillation and a QRS interval greater than 120 ms and LVEF less than 35% with persistent moderate to severe heart failure.\(^3\) Biventricular pacing with defibrillation capability is recommended for patients who meet criteria for biventricular pacing who have also had cardiac arrest or who have evidence of ventricular tachycardia not due to a potentially reversible cause.\(^8\) The decision to implant a biventricular pacemaker with defibrillation capability to prevent sudden cardiac death may also be made for other selected patients. Depending on the model of pacemaker chosen and pacemaker programming, inclusion of defibrillation capability is an elective option. Implanted devices with defibrillating capability are known as cardiac resynchronization therapy defibrillators (CRT-Ds).

### Ventricular Dyssynchrony in Heart Failure

A QRS duration greater than 120 ms in a patient with chronic heart failure may indicate ventricular dyssynchrony (the left and right ventricular contractions do not occur simultaneously and result in impaired ejection). Left bundle branch block is a common cause of QRS duration greater than 120 ms. In left bundle branch block, the left ventricle is activated through the septum, but activation through the left ventricle is delayed, resulting in delayed contraction of the posterolateral left ventricular wall and delayed ejection from the left ventricle compared with the right ventricle. Doppler echocardiography may be used to show ventricular dyssynchrony, but 12-lead ECG evidence of prolonged QRS duration is the gold standard for indicating electromechanical ventricular delay.\(^3\)

When an intraventricular conduction delay is present, coordination in the timing of peak contraction within left ventricular segments is lacking, causing intraventricular dyssynchrony. Additionally, a lack of coordination between left and right ventricular systole, or intraventricular dyssynchrony, occurs. Furthermore, delayed systolic contraction of left ventricular segments results in reduced diastolic filling time with loss of atrial kick (responsible for 25% of ventricular filling). In patients with heart failure, this dyssynchrony may further impair the ability of the left ventricle to pump effectively.

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Mrs P, a 56-year-old woman, had heart failure after cardiac surgery for left coronary artery occlusion and ST-segment elevation myocardial infarction that could not be treated with percutaneous coronary intervention. Although she had completed a cardiac rehabilitation program and insisted that she followed a low-sodium diet and exercise program as instructed, shortness of breath, peripheral edema, and decreased exercise tolerance developed over a period of several months. Twice she was brought to the emergency department of her local hospital because of shortness of breath. During the first visit to the emergency department, she received diuretic therapy and was discharged home. On the second visit, she was admitted to the hospital and was examined by a consulting cardiologist. A 12-lead ECG revealed normal sinus rhythm with a right bundle branch block and QRS duration of 140 ms (Figure 1). A transthoracic echocardiogram indicated an LVEF of 25% and mild to moderate mitral regurgitation.

Implantation of a biventricular pacemaker was recommended to improve Mrs P’s functional status. She consented to the procedure, and a biventricular pacemaker was implanted. Figure 2 shows the results of a 12-lead ECG obtained after the implantation. Two weeks later, Mrs P had a follow-up visit with the cardiologist and stated that she was now able to perform all of her activities of daily living without shortness of breath or fatigue. Echocardiography during the visit indicated that LVEF had increased to 40% and that the mitral regurgitation had decreased. She has been followed up via a telephonic heart failure program and has had no further visits to the emergency department or rehospitalizations.
resulting in decreased cardiac output and stroke volume and an increase in mitral valve regurgitation, which further increases pulmonary venous congestion, resulting in increased backflow and pulmonary congestion. Mitral valve regurgitation in patients with heart failure has multiple causes, including deformation of the mitral valve leaflets due to remodeling, inefficiency of left ventricular contraction, and uncoordinated contraction of the left ventricle. In a study by Bader et al, intraventricular dyssynchrony was the most important independent variable in hospitalization for decompensated heart failure and mortality.

### Biventricular Pacing

A biventricular pacemaker is used for CRT. Unlike traditional permanent pacemakers, which use 2 leads and electrodes to sense and pace the right ventricle, a biventricular pacemaker uses 3 leads and electrodes for pacemaker functions in both the right and the left ventricle (Table 2). Biventricular pacemakers may be CRT-P (pacemaker functions only) or CRT-D. In biventricular pacing, a specifically designed left ventricular lead is inserted through the coronary sinus and then advanced into a coronary sinus vein posteriorly to sense and pace the left ventricle (Figure 3). Benefits of biventricular pacing include increased left ventricular filling time, decreased septal dyskinesis, and reduced mitral regurgitation, although approximately one-third of patients do not have improvement in their cardiac conditions when treated with CRT.

Many studies have shown the effectiveness of biventricular pacing in improving quality of life and decreasing mortality in patients with heart failure. These studies include biventricular pacing both with and without implantable cardioverter defibrillators (Table 3).

### Complications of Biventricular Pacemakers

Compared with implantation of traditional pacemakers, which have leads in the right atrium and right ventricle only, implantation of a biventricular pacemaker involves an additional lead in a coronary vein and thus an increased potential for complications. The most common causes of failure of biventricular pacing include loss of ventricular capture, implant failure, lead dislodgement, and atrial tachyarrhythmias. Unsuccessful implantation is the inability to implant...
the left ventricular lead because the lead cannot be threaded through the coronary sinus and into a coronary sinus vein. Placing the left ventricular lead is technically more difficult than placing the right ventricular lead and may be made more difficult if a patient has left ventricular enlargement, scarring, or atypical coronary sinus or coronary vein anatomy. Coronary sinus dissection or perforation may occur during implantation, and the signs and symptoms may not become evident immediately. Chest pain, shortness of breath, or cardiac tamponade may develop. Signs and symptoms of cardiac tamponade include widening of the mediastinum on chest radiography, jugular venous distension, chest pain, shortness of breath, pulsur paradoxus, and indications of shock. In most instances, loss of synchronization in biventricular pacing can be corrected by alterations in timing. The time delay between the right and the left ventricular stimulus (ie, atrioventricular delay) is programmed for each patient to optimize synchrony of left and right ventricular contraction.

### Optimizing Biventricular Function

In addition to ECG interpretation and pacemaker interrogation (the process for checking on the function

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**Table 3** Studies on biventricular pacemakers

<table>
<thead>
<tr>
<th>Study</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>MADIT-CRT</td>
<td>Reduction in mortality for heart failure events and reduction in the risk of recurrent heart failure events</td>
</tr>
<tr>
<td>MIRACLE</td>
<td>Improvement in exercise tolerance and functional status and decrease in hospitalizations for heart failure</td>
</tr>
<tr>
<td>MUSTIC</td>
<td>Improvement in exercise tolerance, functional status, and quality of life and decrease in hospitalizations for heart failure</td>
</tr>
<tr>
<td>PATH CHF</td>
<td>Increase in exercise tolerance and quality of life</td>
</tr>
<tr>
<td>CONTAK CD</td>
<td>Increase in exercise tolerance and quality of life</td>
</tr>
<tr>
<td>COMPANION</td>
<td>Decrease in mortality and hospitalization for any cause</td>
</tr>
<tr>
<td>CARE HF</td>
<td>Decrease in hospitalizations for heart failure, improvement in functional status</td>
</tr>
</tbody>
</table>

**Table 4** Complications of biventricular pacemakers

<table>
<thead>
<tr>
<th>Complication</th>
<th>Signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local infection at suture site</td>
<td>Fever, redness over pacemaker pocket site, purulent drainage, indications of sepsis (increased white blood cell count, hypotension, tachycardia)</td>
</tr>
<tr>
<td>Systemic infection/sepsis</td>
<td>Increased white blood cell count (&gt; 10.5 cells/μL), fever, hypotension, tachycardia</td>
</tr>
<tr>
<td>Hematoma</td>
<td>Swelling, red or purple discoloration, pain</td>
</tr>
<tr>
<td>Bleeding</td>
<td>Oozing at suture site, hematoma, tachycardia</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>Chest pain, shortness of breath, tachypnea, chest radiographic findings</td>
</tr>
<tr>
<td>Pocket infection</td>
<td>Swelling at insertion site, pain, erythema, ecchymosis, skin erosion</td>
</tr>
<tr>
<td>Lead displacement or fracture</td>
<td>Chest radiographic findings, electrocardiographic findings (failure to capture and failure to sense), chest pain, fatigue, decreased activity tolerance</td>
</tr>
<tr>
<td>Coronary sinus dissection or perforation</td>
<td>Hypotension, cardiac tamponade, chest radiographic findings</td>
</tr>
<tr>
<td>Implant failure</td>
<td>Failure to pace in the left ventricle, fatigue, activity intolerance, syncope</td>
</tr>
<tr>
<td>Cardiac tamponade</td>
<td>Jugular venous distension, narrowed pulse pressure, hypotension, chest radiographic findings, shortness of breath, chest pain</td>
</tr>
<tr>
<td>Venous occlusion</td>
<td>Arm swelling, pain, cyanosis</td>
</tr>
<tr>
<td>Electromagnetic interference</td>
<td>Palpitations, syncope, electrocardiographic changes including asynchronous pacing at preset rate</td>
</tr>
<tr>
<td>Phrenic nerve stimulation</td>
<td>Hiccups, abdominal pain, or cramps</td>
</tr>
</tbody>
</table>
of a pacemaker to make sure it is working properly and the batteries are in good condition), echocardiography is used to determine the functional effectiveness of biventricular pacemakers. Surface or transthoracic echocardiography is generally used to determine cardiac output and ejection fraction. Echocardiography is used to show optimization of left ventricular diastolic filling and ejection. It also indicates decreases in mitral regurgitation and the adequacy of the programmed atrioventricular delay. Pacemaker timing intervals, which are important in biventricular pacing, include atrioventricular delay, a parameter that starts with the atrial event and then is programmed to determine the time to ventricular response. Atrioventricular delay is programmed for each patient to optimize synchrony of left and right ventricular contraction. The atrioventricular delay may be programmed to be rate responsive to support a patient when his or her heart rate increases. Echocardiography indicates the cardiac output in relation to increases in heart rate to determine a patient’s ability to adapt to increases in heart rate when performing activities of daily living.

**Assessment of Biventricular Pacemaker Function**

Commonly, patients experience decreased exercise tolerance or fatigue when their biventricular pacemaker is not functioning optimally. They may be admitted to the hospital for shortness of breath or other signs and symptoms of heart failure, such as weight gain or lower extremity edema. If any question exists that the pacemaker is not functioning properly, a 12-lead ECG should be obtained, and a cardiologist should be contacted to review the ECG findings and determine if pacemaker interrogation is needed. In interrogation, a device is used to give information on lead integrity, battery life, and number of instances of atrial or ventricular tachyarrhythmia (Figure 4).

A 12-lead ECG is the most readily available method to determine if the pacemaker is functioning properly. Pacing spikes for both the right and the left ventricle should be evident and enable a nurse to determine if the device is pacing and capturing appropriately. When biventricular pacemakers were first implanted, it was not always evident that both right and left atrial chambers were being paced as there was no programmed delay between right and left atrial pacing. The left atrial pacing spikes and left ventricular pacing spikes were predominant in the 12-lead ECG. Now, most often data from both the right and the left ventricle are evident in the 12-lead ECG because cardiologists program the pacemaker to ensure a minimal delay that enables pacemaker spikes from both ventricles to be evident on the ECG. Data collected from the left and right ventricular leads of the pacemaker may be seen in ECG leads I and III, so monitoring in leads I and III may be beneficial to assess the function of a biventricular pacemaker. During biventricular pacing, ECG lead V1 should show a tall R wave, and right axis deviation should be evident in the 12-lead ECG. A negative QRS complex in lead V1 in a patient with a biventricular pacemaker can occur if the V1 electrode is placed too high on the chest; other possible causes are failure of the left ventricular pacing lead, misplacement of the left ventricular lead, and delay due to scarring of myocardial tissue around the left ventricular electrode.

When a patient with a biventricular pacemaker is admitted because of decompensated heart failure, the cause of the heart failure should be considered. The failure could be due to malfunctioning of the pacemaker, lack of adherence to medical therapy, or other causes such as infection. The patient should be asked if he or she has complied with dietary and medication therapies. A 12-lead ECG should be obtained and reviewed to determine pacemaker function. If a tall R wave and right-axis deviation are not present, a physician should be contacted.
because these findings may indicate the need for pacemaker interrogation to determine the function of the biventricular pacemaker and the need for further studies or pacemaker interrogation. Other determinations to be made include the following: Is the QRS interval greater than 120 ms duration, indicating ventricular activation of the impulse? Are pacemaker spikes present, and can the spikes be seen in all 3 chambers (right atrium, right ventricle, and left ventricle)?

Application of a magnet over the pacemaker should cause the biventricular device to pace at a programmed rate (an asynchronous ventricular rate). Patients with an implanted cardioverter-defibrillator have a different response to the magnet. Generally there is a single tone when defibrillation is not activated and a pulsed tone with the heart rate when defibrillation is activated. The magnet does not turn the pacemaker off permanently. In the case of death, the pacemaker must be programmed off. The preprogrammed rate depends on the manufacturer or model of the pacemaker, so the patient’s medical record should be checked to see if information on the pacemaker is available. If access to the information is not available but access to the patient’s device type and model is available on a wallet card (should be carried by every patient with a pacemaker of any type), the manufacturer can be contacted to obtain the needed information. Some pacemakers respond to application of a magnet by enabling access to stored information on the pacemaker’s function without initiating a preprogrammed pacing rate. The manufacturer can be contacted to determine if this feature of the pacemaker is the reason application of the magnet does not cause pacing at a preprogrammed rate.

Rhythm strips and a 12-lead ECG should be obtained during application of the magnet. If no pacemaker spikes are evident after magnet application, the battery may be depleted or fracture of a pacemaker lead may have occurred. Lead fracture or displacement may be evident on a chest radiograph (Figure 5). Displacement of the lead from the pacemaker may occur if the patient has experienced overextension of the left arm or trauma. ECG leads I and III should both be monitored. If the patient has an elevated body temperature or redness or drainage over the insertion site of the pacemaker generator, pocket infection or sepsis may have occurred. The hospital’s protocols for sepsis should be followed

![Figure 5 Chest radiograph shows biventricular pacemaker.](image)

Table 5 Assessment of biventricular pacemakers

<table>
<thead>
<tr>
<th>Method</th>
<th>Clinical Findings</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiography</td>
<td>Indications of lead dislodgement or fracture</td>
<td>Contact physician if radiographic findings suggest lead dislodgement or fracture</td>
</tr>
<tr>
<td>12-Lead electrocardiography</td>
<td>Pacemaker spikes in 3 chambers</td>
<td>Contact physician to obtain orders for pacemaker interrogation from manufacturer’s representative or cardiology consultation</td>
</tr>
<tr>
<td></td>
<td>Pacemaker spikes not evident in right atrium or either ventricle</td>
<td>Obtain orders for 12-lead electrocardiography with magnet</td>
</tr>
<tr>
<td>Telemetry or continuous electrocardiographic monitoring</td>
<td>Pacemaker spikes not evident in lead I or lead III Failure to pace at preset rate when magnet applied over pacemaker</td>
<td>Contact physician to inform of pacemaker malfunction and need to contact manufacturer for interrogation May need to contact cardiologist for possible retiming or battery replacement</td>
</tr>
<tr>
<td>Physical assessment</td>
<td>Decreased activity tolerance, increased shortness of breath, increased indications of pulmonary congestion</td>
<td>Determine cause of increased indications of heart failure (device failure, compliance failure or other cause such as infection) Contact physician with clinical data such as electrocardiographic, chest radiographic, laboratory findings or physical findings such as fever, skin redness, or purulent drainage at pacemaker insertion site</td>
</tr>
</tbody>
</table>
if indicated. Table 5 provides information on assessment of biventricular pacemakers, including methods of assessment, clinical findings, and interventions.

**Conclusion**

Biventricular pacemakers are becoming increasingly common in the treatment of patients with heart failure. Critical care and telemetry nurses should be aware of the function of biventricular pacemakers and of assessment findings when the pacemakers malfunction to ensure that the nurses are able to communicate to a physician what additional diagnostic activities are needed to ensure appropriate patient care. Nurses who provide care for patients immediately after insertion of a biventricular pacemaker must also be aware of added complications associated with the implantation, such as coronary sinus vein dissection and cardiac tamponade. Assessment of the patient and of the functioning of the biventricular pacemaker is essential to ensure appropriate patient care. Online education on pacemakers is available (eg, www.medtronicacademy.com).

**Financial Disclosures**

None reported.

**References**


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1. Which of the following are causes of intraventricular dyssynchrony?
   a. Timing of peak contraction of left ventricle
   b. Delayed systolic contraction of left ventricle
   c. Delayed activation of left ventricle
   d. All of the above

2. Which of the following is a complication specifically associated with biventricular pacemaker implantation?
   a. Coronary vein rupture
   b. Inappropriate timing
   c. Coronary sinus dissection
   d. Hematoma

3. Which of the following are involved in lead placement in biventricular pacing?
   a. Right atrium, right ventricle, and left ventricle
   b. Right ventricle, coronary sinus, and left ventricle
   c. Right atrium, right ventricle, and posterior cardiac vein
   d. Right atrium, left atrium, and left ventricle

4. Which of the following should be assessed to determine malfunction of biventricular pacing?
   a. Rhythm disturbance with onset of heart failure symptoms
   b. Impulse activation and presence of pacing spikes in the right atrium, right ventricle, and left ventricle
   c. Presence of left axis deviation and left bundle branch block (LBBB)
   d. Placement of pacing lead wires

5. According to the American Heart Association, indications for biventricular pacing include which of the following?
   a. Left ventricular ejection fraction (LVEF) <35%, right bundle branch block, QRS duration >130 ms, heart failure class II
   b. LVEF <35%, QRS duration >150 ms, heart failure class II
   c. LVEF <35%, LBBB, QRS duration >150 ms, heart failure greater than class II
   d. LVEF <35%, LBBB, QRS duration >120 ms, heart failure class III and IV

6. Ventricular dyssynchrony is an important variable in decompensated heart failure because it leads to which of the following?
   a. Mitral valve regurgitation
   b. Inappropriate timing of systole and diastole
   c. Impaired diastolic filling and loss of atrial kick
   d. Increased mortality in heart failure patients

7. A patient with a history of ventricular tachycardia develops class II heart failure. Echocardiogram shows LVEF of 30% with delayed contraction of the left ventricle. What form of pacemaker therapy would most benefit this patient?
   a. Biventricular pacemaker to synchronize left and right ventricular contraction
   b. Cardiac resynchronization therapy defibrillator
   c. Cardiac resynchronization therapy pacemaker
   d. Patient has class II heart failure and is ineligible for therapy

8. Benefits of biventricular pacemaker therapy include which of the following?
   a. Increased cardiac output and stroke volume
   b. Improved contraction of right and left ventricle
   c. Increase in left ventricular filling and decrease in septal dyskinesis
   d. Improved stroke volume and contraction of right ventricle

9. Which of the following leads to intraventricular dyssynchrony?
   a. Loss of atrial kick
   b. Decreased cardiac output
   c. Impaired diastolic filling and loss of atrial kick
   d. Lack of coordination in timing of peak contraction within left ventricular segments

10. Which of the following parameters is most integral to optimize synchronization of the left and right ventricle?
    a. Rate responsiveness
    b. AV delay
    c. Optimal left ventricular diastolic filling
    d. LVEF
Biventricular Pacemakers in Patients With Heart Failure
Karen Leslie Cooper

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