Biventricular Pacemakers Sensing

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Left ventricular pacemaker lead technology was evolving and different types of pacemaker lead were successively used. Sensing was modified according with this evolution, starting with initial experience that utilized epicardical left ventricular pacing through leads positioned at limited thoracotomy [1]. In other experiences a lead specifically designed for left atrial pacing via CS was used. This tine-free lead has a bipolar, coaxial polyurethane-coating with a 5.8 mm non-steroid eluting canted electrode tip [2-3].

Another step was a tine-free unipolar polyurethane coated coaxial lead designed specifically for left ventricular pacing via the coronary sinus (figure 1). To aid with CS cannulation, a specifically designed guiding sheath was employed. This sheath is pre-shaped to facilitate CS entry, thus allowing pacemaker lead placement through its lumen. After pacemaker lead positioning the sheath can be pulled back and split externally along its entire length to allow separation from the underlying pacing lead. [4,5]. In addition the lead used was of a novel design with a terminal adaptation allowing lead passage over a pre-positioned guidewire (side-wire pacing leads) [6].

Leclerck et al used a modified transeptal technique more complex and without long term follow-up [7,8].

Although at the present time, most of the pacemakers have a three lumen head (with different type of sensing functions) during initially experiences standard DDDR devices were employed where the left ventricular lead was connected to the atrial port of the device and the right ventricular lead was connected to the ventricular port. Setting the AV delay to its minimum near simultaneous biventricular capture could be achieved. Unipolar or bipolar pacing and sensing could be used dependent on the pacemaker lead utilized. [9]

In the PATH-CHF study [10,11] 2 DDDR pacemakers were implanted in all patients. The first pacemaker was implanted and connected to a right atrial bipolar lead and to a unipolar right ventricular lead. The second pacemaker was implanted and connected to a second bipolar right atrial lead and a unipolar ventricular epicardial lead. Atrial sequential biventricular pacing could be initiated by setting one pulse generator to DDD mode while the other was programmed in VVT mode. Sensing could be adjusted according to each individual lead.

Another step was the use of a Y connection for right and left ventricular leads in a single DDDR pacemaker,
with simultaneous pacing and sensing in both ventricles.

Actually, a three chamber pacemakers with three lumen head are used and sensing vary from different models: all of them have bipolar (programmable to unipolar if required) sensing in right atrium; but some of them have unipolar sensing at the left ventricle independent of the RV sensing (usually bipolar); some have bipolar sensing between the RV and the LV tip lead and some of them RV-only sensing, as shown in table I.

<table>
<thead>
<tr>
<th>MANUFACTURER</th>
<th>MODEL</th>
<th>SENSING</th>
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</thead>
<tbody>
<tr>
<td>Biotronik</td>
<td>Tachos MSV</td>
<td>RV-only sensing</td>
</tr>
<tr>
<td>ELA</td>
<td>Talent MSP</td>
<td>RV-only sensing</td>
</tr>
<tr>
<td>Guidant</td>
<td>Contak CD</td>
<td>simultaneous LV+RV sensing</td>
</tr>
<tr>
<td>Medtronic</td>
<td>InSync</td>
<td>RV-only sensing</td>
</tr>
<tr>
<td>St. Jude</td>
<td>Frontier</td>
<td>simultaneous LV+RV sensing</td>
</tr>
</tbody>
</table>

Table I: Sensing options in different biventricular pacemaker models

Sense configurations are shown in table II

<table>
<thead>
<tr>
<th>CHAMBER</th>
<th>POLARITY</th>
<th>SENSING</th>
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<tr>
<td>RV</td>
<td>Bipolar</td>
<td>TIP AND RING</td>
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<tr>
<td>RV</td>
<td>Unipolar</td>
<td>TIP AND CASE</td>
</tr>
<tr>
<td>RV</td>
<td>Bipolar</td>
<td>TIP AND COIL (ICD DEVICES)</td>
</tr>
<tr>
<td>LV/RV</td>
<td>Bipolar</td>
<td>RV TIP / LV TIP</td>
</tr>
<tr>
<td>LV</td>
<td>Bipolar</td>
<td>TIP AND RING</td>
</tr>
<tr>
<td>LV</td>
<td>Unipolar</td>
<td>RING AND CASE (Frontier)</td>
</tr>
<tr>
<td>LV</td>
<td>Unipolar</td>
<td>TIP AND CASE</td>
</tr>
<tr>
<td>LV</td>
<td>Unipolar</td>
<td>NO SENSING</td>
</tr>
</tbody>
</table>

Table II: Sense configuration for all combinations of right and left ventricular lead types

SENSITIVITY

Overview

If a cardiac signal of sufficient amplitude and morphology occurs during the sensing period, the pacemaker output will be inhibited or triggered depending upon the mode selected. The sensing circuit is specially designed to reject extraneous signals while sensing P waves or R waves.

Sensitivity determines the minimum intracardiac signal that the device can detect when intrinsic atrial or ventricular events occur. The higher the mV value, the lower the sensitivity. When sensitivity is programmed to a very sensitive setting (a low value) the device may detect signals unrelated to cardiac depolarization (oversensing: e.g., sensing of myopotentials). When sensitivity is programmed to a less sensitive setting (a higher value) the device may not detect the cardiac depolarization signal (undersensing). Sensitivity must be programmed to a value that prevents sensing of extraneous signals, but ensures accurate sensing of intrinsic cardiac signals. Intrinsic atrial signals are typically smaller than ventricular signals, so lower sensitivity settings are typically programmed for the atrium.

Left ventricular signals are typically smaller than right ventricular signals. In some devices this is an independent value but in others, the measurement is a combination of signals from the left and right ventricles and ventricular signal may be attenuated (reduced). So, sensitivity settings should be programmed according this situation.

Whether selecting sensing parameters at implant or verifying sensing at follow-up, the same considerations apply:

a. Select sensing polarity for leads
b. Determine sensing thresholds
c. Select appropriate sensitivity settings

A. Selecting Sensing Polarity

Atrial and ventricular sensing polarities can be programmed for each chamber when used with bipolar leads.
**Bipolar Sensing Polarity** - The lead tip and the lead ring electrode are the poles of the sensing circuit. Because bipolar sensing is more localized, it reduces the likelihood of sensing myopotentials and electromagnetic interference. It may also permit sensitivity to be programmed to a more sensitive setting.

**Unipolar Sensing Polarity** - The lead tip (occasionally the lead ring) and the noninsulated stimulator case are the sensing electrodes. Unipolar sensing may allow sensing of smaller intrinsic signals than does bipolar sensing and therefore, can be selected when intrinsic cardiac signals are difficult to detect with bipolar sensing. Oversensing due to myopotentials is more common with unipolar sensing than with bipolar sensing.

**Bipolar RV/LV Sensing Polarity** - In the LV-1 lead, the electrical activity will be sensed between the lead tip and the right ventricular lead ring. The distance the stimulus travels between the lead tip and the right ventricular lead ring will be affected by the size of the heart. The greater the distance, the more prone the device is to sensing myopotentials.

**Bipolar Sensing Polarity Confirmation**
Before programming from unipolar to bipolar sensing, some of the programmer verifies the presence of a functioning bipolar lead by testing impedance for the lead. Testing is done under magnet operation for four seconds at an Amplitude of 5.0 V and a Pulse Width of 1.0 ms if the permanent settings are at or below this level.

If permanent settings are above these values, the measurement will be made at the permanent settings.

If bipolar lead impedance is between 200 ohms and 3000 ohms, a bipolar lead is assumed to be present.

If bipolar lead impedance is outside this range, a unipolar lead is assumed to be present. The programmer warns that the test failed, and sensing polarity remains set to unipolar.

This interlock feature may be overridden and lead sensing polarity forced to bipolar.

Impedance for the ventricular two-lead system is measured across the parallel combination of both leads in most devices. However, if pairing a ventricular lead with a polished platinum tip electrode with a lead with a tip electrode of a different material may create a source impedance mismatch that could adversely affect sensing.

**B. Determining Sensing Threshold(s) at Implant**
Before connecting a lead, implanting physician should measure the sensing potentials in the unipolar and the bipolar configurations. Adequate intracardiac signal should be present in both configurations to ensure proper sensing in either.

**Verifying Sensing Threshold(s) at Follow-up**
Intracardiac signal amplitudes decrease during the lead maturation process. Most programmers provide an automatic sensitivity test that allows the follow-up clinician to verify a patient's sensitivity settings. The automatic test provides for atrial or ventricular monitoring. The test provides the sensitivity setting just above and below the point at which P waves or R waves are sensed.

The cardiac signal presented to the stimulator by the ventricular two-lead system is a composite signal from the parallel combination of both ventricular leads in some devices. The sensing test treats this signal as a single input with a measurable amplitude that can be used to determine an appropriate setting for ventricular sensitivity. Usually this signal may be attenuated (reduced) in the biventricular configuration. Conducting the Sensing test for the ventricular two-lead system does not require any special considerations.

**C. Selecting Sensitivity Settings**
Atrial and ventricular sensitivity are independently programmable. In general, a 2:1 to 3:1 sensitivity safety margin (threshold sensitivity value divided by 2 or 3) is adequate for newly implanted or chronic leads. For example, an atrial sensitivity of 1.0 mV should be satisfactory for intrinsic atrial signals between 2.0 mV and 3.0 mV.

Ventricular sensitivities 1.0 mV or 1.4 mV with wide atrial pulse widths or high atrial amplitudes may result in Ventricular Safety Pacing (if On) with some lead systems at high sensor-driven pacing rates. Reprogramming Ventricular Sensitivity to a less sensitive setting (higher numerical value) is one option under such circumstances. Other options include programming a longer Ventricular Blanking Period.
Excessively sensitive (low) settings can cause some or all of the following problems:

- oversensing due to electromagnetic interference (EMI), myopotentials, T waves, or crosstalk
- undersensing due to overloading of the sensing circuit
- noise reversion operation

**Effects of Myopotentials During Unipolar Pacing**

Myopotentials can affect device operation when sensing polarity is unipolar, especially with atrial sensitivity settings of 0.5 through 1.0 mV and ventricular sensitivity settings of 1.0 and 1.4 mV.

Myopotentials sensed on the atrial channel outside the total atrial refractory period (SAV + PVARP) start sensed AV intervals in the DDDR, DDD, and VDD modes.

Continuous myopotentials cause reversion to asynchronous operation when sensed in the refractory period:

- on the ventricular channel at intervals less than the ventricular refractory period in the DDDR, DDD, DDIR, DDI, DVIR, DVI, VDD, VVIR, VDIR, VVI, VDI, and VVT modes,
- on the atrial channel at intervals less than the atrial refractory period in the AAIR, ADIR, AAI, ADI, and AAT modes.

In the VVIR and VDIR modes, the resulting asynchronous pacing occurs at the Lower Rate, otherwise such asynchronous pacing occurs at the sensor-indicated rate for rate response modes or the Lower Rate for non-rate response modes.

**Refractory Periods**

Pacemakers with a sensing mode incorporate a programmable parameter known as the refractory period.

The refractory period is the interval following a paced or sensed event during which the device is not inhibited or triggered by detected electrical activity. The purpose of the refractory period is to prevent resetting of the pacemaker timing cycles in response to known but physiological inappropriate electrical signals.

Pacing refractory periods prevent certain pacing timing intervals from being started by inappropriate sensed signals such as far-field R-waves or electrical noise. Synchronization refractory periods help prevent delivery of pacing or shock pulses during the atrial and ventricular vulnerable periods.

In some cases, the programmer will automatically select refractory periods suitable to the programmed parameters.

In the AAT, AAI and AAIR modes, the **Atrial Refractory Period (ARP)** is defined as the time period after an atrial event, either paced or sensed, when activity in the atrium does not inhibit or trigger an atrial stimulus. It prevents inappropriate atrial inhibition due to sensed far-field R-waves or electrical noise. The first portion of the ARP is a blanking period that disables atrial sensing.

**Ventricular Refractory Period (VRP):** Is defined as the time period following a ventricular event, either paced or sensed, when sensed electrical activity in the ventricles does not inhibit the device. This parameter is available in any mode in which ventricular sensing is enabled and the interval is programmable in all biventricular devices but not in all ICD-biventricular devices.

Use a long ventricular refractory period shortens the ventricular sensing window. Programming the ventricular refractory period to a value greater than PVARP can lead to competitive pacing.

In dual chamber pacing modes, the Post-Ventricular Atrial Refractory Period (PVARP) controls how the device responds to retrograde P-waves. It is defined as the time period after a ventricular event, either paced or sensed, when activity in the atrium does not inhibit a retrograde stimulus or trigger a ventricular impulse. It is designed to prevent the atrial channel from sensing the ventricular pacing pulse, the far-field R-waves or retrograde P waves.

The **Post-Ventricular Atrial Blanking (PVAB) period** acts as the minimum PVARP value. Sensed atrial events that fall within the PVAB period are ignored by the Mode Switch, PVC Response, PMT intervention, and NCAP features, but are used for dual chambers.

**Chamber SVT Criteria**
Blanking Periods
Blanking is the first part of the refractory period, where sense amplifiers are completely disabled. It is used to prevent cross-chamber sensing and inhibition.

During a blanking period the device does not sense electrical signals. Blanking periods avoid sensing ICD outputs, post-pacing polarization, T-waves, and multiple sensing of the same event.

During a blanking interval, the sensing circuit in one chamber ignores sensed electrical activity generated by a device pulse in the other chamber (cross-talk).

The blanking periods following paced events are longer than those following sensed events to avoid sensing the depolarization signal on the electrodes.

Some devices to enhance sensing and detection during tachyarrhythmias, do not cross-blank (blank sensing in the opposite chamber) after a sensed event.

During the programmable "Post-Ventricular Atrial Blanking" (PVAB) period, the atrial sensing circuit is active.

Ventricular blanking after atrial pace: In the ventricles, the atrial pace concurrently starts a retriggerable noise rejection interval and a programmable ventricular blanking interval.

Atrial blanking after ventricular pace: In the atrium, the ventricular pace concurrently starts a retriggerable noise rejection interval and a programmable atrial blanking interval

Noise rejection
The pulse generator’s noise response functions designed to protect the patient against inappropriate inhibition of the pulse generator due to detected rapid electrical interference signals or "noise". Noise rejection works through the programmable refractory period, that is composed of two segments: the absolute refractory period and the relative refractory period. In the absolute refractory period no signals will be detected. Any electrical signals occurring within the relative refractory period will initiate a noise-sampling window beginning at the point where the noise signal was detected.

Hence, in the presence of continuously detected electrical noise, the refractory period will be repeatedly reset until the escape interval is complete, resulting in asynchronous pacing at the programmed mode and base rate. The pacemaker will continue monitoring for noise. When noise is no longer detected, the pacemaker will resume normal operation at the programmed parameters.

PACING: In both, the atrium and the ventricles, a pace concurrently starts a fixed noise rejection interval followed by a programmable retriggerable noise rejection interval in the paced chamber.

SENSING: when an atrial depolarization is sensed, a noise rejection interval is started in the atrium. This interval is retriggered in the continued presence of noise. When a ventricular depolarization is sensed, a noise rejection interval is started in both the atrium and the ventricles. This interval is retriggered in the continued presence of noise.

ADVANTAGES, PITFALLS AND SOLUTIONS
Sensing in RV only or in both ventricles, together or separately, during pacing or in sinus rhythm should modify the response of the system. The differences of these situation are explained as well as double counting of T waves and farfield noise.

UNDER DETECTION DUE TO SPONTANEOUS VENTRICULAR BEATS IN RV-ONLY SENSING: A system that senses RV-only do not see any beat (ectopic) that is originated in the Left Ventricle and may stimulate it over the refractory period. On the other hand, any intrinsic ventricular action inhibits delivery of a ventricular pulse in the DDD mode. The ventricles are not brought into synchrony with each other.

OVER DETECTION DUE TO LV+RV SENSING: A system that senses both the RV and LV leads in the presence of a QRS>130 msec may double sense a sinus rhythm contraction. This situation is true only when the patient’s P-R interval is shorter than the programmed AV delay and/or there are no pacing beats at the ventricles. A similar situation could be seen if the sensing delay of both ventricles is greater than the ventricular refractory period (programmable in ICD but not in all the pacemakers).
However, in both cases there are no RCT due to the fact that there are no pacing beats.

**SOLUTIONS:** Although optimal performance of biventricular devices' sensing has yet to be determined, some companies modified the sensing system to avoid these problems and other introduced de DDT(R)/V mode and the LV protection period.

The DDT(R)/V mode has been specially designed to ensure biventricular synchronization. Is a permanent rate-adaptive pacing mode that represents a combination of the DDDR mode with a VVT mode. In DDT (R)/V mode, the pacemaker triggers a ventricular pace when the AV interval completes without sensing an intrinsic ventricular event. Furthermore, intrinsic right and left ventricular senses trigger a biventricular pace within 10 msec. So, the pacemaker response in the ventricular channel corresponds to a VVT mode, and its atrial or its AV-sequential behavior is analogous to a DDD mode. The clinical benefit of the DDT(R)/V mode is based on the ability to resynchronize both ventricles even during ventricular sense events.

![DDT(R)/V-Mode and DDD(R)-Mode](image)

**Figure 2:** The first beat shows an atrial and ventricular pacing without sensing an intrinsic ventricular beat; the second shows a P sensed followed by an intrinsic ventricular beat that triggers a biventricular pace within 10 msec.

**LEFT VENTRICULAR PROTECTION PERIOD:** Sensing on the LV could avoid a pace over the refractory period after a PVC’s. The following example could help to understand the case: in the presence of a PVC’s originated in the lateral wall of the LV, if the device senses only the RV will not see the ectopic beat and will pace the RV and then the LV (that will be during the vulnerable period). To avoid this situation, some devices sense the LV and let you to program the refractory period during which there are no chance to stimulate the LV if there was a sensing activity.

**EXTENDED SENSING OPTIONS**
Some devices has additional features to optimize the sensing functions

**MANUAL OR AUTO-ADJUSTING SENSITIVITY THRESHOLDS:**
Especially in cases of T-wave oversensing, the ventricular thresholds can be modified. In some devices, the ventricular thresholds can be manually reduced to different levels (75, 50, 37 or 25%) and a second and third halting periods can be adjusted. Others, with auto-adjusting capacity, thresholds increase dramatically and then gradually return to their programmed values, having been adjusted by the preceding sensed or paced event, as shown in figure 3.
EARLY FARFIELD TOLERANCE: This parameter declares all atrial signals that occur just before the QRS complex and are within the range of tolerance to be farfield signals. When necessary, this parameter allows a 1:1 rhythm to be classified as such without incorrectly assuming 2:1 atrial flutter.

ATRIAL BLANKING AFTER VENTRICULAR SENSE: If QRS farfields are observed even though the atrial lead used has a short electrode distance, Ablank after Vsense can be activated. The atrial blanking period should be kept as short as possible, it should be set only as long as necessary for each individual. An additional safety measure for the scenario described is the programmable "INCREASED ATRIAL STARTING SENSITIVITY" directly after Ablank after Vsense expires.

References

7. Gold M, Rashba E: Left ventricular endocardial pacing: don't try this at home. PACE 1999; 22: 1567-69

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