Selective Atrial Sensing in Dual Chamber Pacemakers Eliminates Endless Loop Tachycardia

PETER T. KLEMENTOWICZ, MD, SEYMOUR FURMAN, MD, FACC
Bronx, New York

Continuous effective atrial sensing is a necessary condition for proper functioning of a dual chamber pacemaker. The sensing of an atrial signal initiates a number of timing intervals and activates the atrioventricular (AV) interval timer. If a ventricular signal is not identified during the programmed AV interval, the pulse generator emits a ventricular stimulus at the end of the AV interval, pacing the ventricle. If a ventricular signal is sensed during the AV interval, the pulse generator remains quiescent. In this manner, AV synchrony and rate-responsive pacing (1), the major advantages of dual chamber pacing, are maintained. When the atrial signal is not sensed, the pulse generator will pace the atrium, competing with the intrinsic atrial rhythm (2), disrupting AV synchrony and undermining rate-responsive pacing. Conversely, the sensing of retrograde atrial signals can initiate and sustain endless loop tachycardia (3,4).

The amplitude of the atrial endocardial signal is one of the major criteria necessary to ensure signal recognition by the sensing amplifier. With the introduction of pacemakers with multiple atrial amplitude sensitivity settings, it is theoretically possible to sense selectively those signals with sufficient amplitude and reject those of lesser amplitude. We have previously demonstrated (5) that there is a difference in the amplitude of anterograde and retrograde P waves in the majority of patients with an implanted dual chamber pacemaker. To demonstrate the clinical utility of selective atrial sensing, we prospectively evaluated five patients whose anterograde atrial signal was at least 1.4 times larger than its corresponding retrograde atrial signal and who had investigational devices capable of discriminating this difference. We have shown that by carefully programming the atrial sensitivity settings, anterograde atrial signals can be continuously sensed and retrograde signals ignored, thus eliminating endless loop tachycardia.

Methods

Patient selection criteria. We evaluated consecutive patients who: 1) needed a dual chamber pacemaker, 2) were not taking cardiac medications, 3) had retrograde conduction in which the amplitude of the anterograde atrial signal was at least 1.4 times larger than that of the retrograde atrial
signal, and 4) had implantation of a dual chamber pulse
generator with multiple atrial amplitude sensing values.

Implantation technique and measurements. Informed
written consent was obtained from all patients before im-
plantation of the pacemaker and the leads were inserted in
the standard manner. Using fluoroscopic guidance, the atrial
lead was positioned in the right atrial appendage and the
ventricular lead was positioned in the right ventricular apex.
Endocardial electrograms were recorded on photographic
paper at 200 mm/s using a physiologic recorder (Electronics
for Medicine) that has a passband of 0.1 to 2,000 Hz. The
peak to peak amplitude of the anterograde and retrograde
atrial signals was determined as previously described (6,7).
The existence of retrograde conduction was determined by
recording the atrial electrogram during incremental ventricu-
lar pacing (8).

Pulse generator. An investigational pulse generator that
has multiple atrial amplitude sensitivity selections, either
the CPI 925 (Cardiac Pacemakers, Inc.) or the CCS 501
(Cardiac Control Systems, Inc.) was implanted in all pa-
tients. The CPI 925 pulse generator has 26 atrial sensitivity
settings, ranging from 0.25 to 15 mV. Its sensing amplifier
is calibrated with a 25 Hz haversine signal and the tolerance
is 0.25 mV or 40%, whichever is greater. The CCS 501
has 16 atrial amplitude sensing selections ranging from 0.5
to 25.0 mV. In addition to amplitude discrimination, the
unit has a programmable passband filter allowing for low
frequency selection (20 to 110 Hz) or high frequency se-
lection (40 to 200 Hz). The low frequency amplifier is
calibrated with a 25 Hz haversine signal and the high with
a 50 Hz haversine signal. The amplitude tolerance with the
low frequency filter setting is 20% for settings greater than
0.5 mV and 50% for the 0.5 mV setting.

Pacing protocol. The pacemakers were programmed in
the DDD mode with a unipolar lead configuration. After
implantation, the pulse generator output was programmed
sufficiently above stimulation threshold to ensure continued
effective pacing in the early postoperative period (9). The
postventricular atrial refractory interval was selected to be
shorter than the patient's minimal retrograde conduction
time. The upper rate limit was less than 115 beats/min. Two
atrial sensitivity selections were evaluated in each patient:
one to ensure sensing of both anterograde and retrograde P
waves and one to allow sensing of anterograde P waves
only. In patients with the CCS 501 pulse generator the pacem-
aker was programmed for the low passband filter atrial
sensitivity setting. Ambulatory electrocardiographic (Hol-
ter) monitoring was performed on 2 consecutive days and
the sequence of atrial sensitivity settings was randomly
assigned.

Holter monitoring. The Holter monitor electrocardio-
graphic tapes were analyzed with a microprocessor-based
scanner that has full disclosure capability (Trendsetter, model
DCG VII). The tapes were displayed in 3 minute increments
at 10 to 20 times magnification. All episodes of atrial sensing
abnormalities and endless loop tachycardia were printed on
a chart recorder for analysis and quantification. The duration
of the study, number of beats and number of atrial under-
sensing episodes were recorded, as was the duration of each
episode of endless loop tachycardia. The transcriptions were
reviewed independently by the authors.

Results

Patient selection. All patients satisfied the selection cri-
tera, all were men and the mean age was 70.8 years. The

Figure 1. Simultaneous atrial elec-
trogram (top) and lead II electrocar-
diogram (bottom). Three hundred
forty milliseconds after the ventric-
ular stimulus (Stv), retrograde P
waves with an amplitude of 2.5 mV are
recorded on the atrial electrogram.
When the ventricular pulse duration
is decreased below stimulation thres-
hold, retrograde conduction ceases
and anterograde P waves with an
amplitude of 4.2 mV resume.

\[ \text{IDA(ANTE) = intrinsic deflection of anterograde atrial signal; IDA(RETRO) = intrinsic deflection of retrograde atrial signal.} \]
indication for pacemaker implantation was second degree heart block in three patients, complete heart block in one patient and symptomatic sinus bradycardia in one.

**Initial implantation data.** The amplitude of the anterograde P waves was at least 1.4 times larger than that of the corresponding retrograde P waves. The mean ratio of the amplitude was 1.9 (range 1.4 to 2.7). The mean amplitude of the anterograde atrial signal was 4.6 mV (range 2.3 to 7.4), whereas the mean amplitude of the retrograde signal was 2.4 mV (range 1.4 to 3.3). On average, the anterograde signal was 2.2 mV larger than the retrograde signal (Fig. 1).

Each patient’s minimal ventriculoatrial (VA) conduction time is listed in Table I. The average VA conduction time was 260 ms (range 200 to 335). The retrograde conduction time was prolonged with incremental ventricular pacing and, in all patients, retrograde block occurred at a ventricular pacing rate exceeding 120 beats/min.

**Pacer settings.** All five patients’ pacemakers were in the DDD mode with a unipolar atrial lead configuration. The mean duration of the postventricular atrial refractory interval was short, 112 ms (range 60 to 200). The patients’ minimal VA conduction time was at least 100 ms longer than the programmed postventricular atrial refractory interval. The mean upper rate limit was programmed to 96 beats/min (range 80 to 115). This was well below the rate at which retrograde block occurred.

**Holter monitor results.** All patients had endless loop tachycardia when the atrial sensitivity selection was high (Table 1). The mean number of episodes of tachycardia per patient was 41 (range 6 to 143). The mean duration of the tachycardia was 118 beats. There were no episodes of atrial undersensing. When the atrial sensitivity setting was decreased, sensing of retrograde P waves was eliminated and endless loop tachycardia did not occur. There was sporadic atrial undersensing with the lower atrial sensitivity setting. On average, atrial undersensing occurred 1.5 times for every 1,000 P waves. The atrial undersensing did not produce atrial arrhythmia.

**Discussion**

Continuous adequate atrial sensing depends on several features of the atrial signal: amplitude, slew rate and frequency content (10). When minimal criteria are satisfied, the atrial endocardial signal is identified by the atrial sensing amplifier and the appropriate timing cycles are initiated. A sensed atrial signal initiates the atrioventricular timing interval. If, after the programmed AV delay, no ventricular signal is identified by the ventricular amplifier, a ventricular stimulus is generated. Conversely, sensing of the ventricular signal during the AV interval inhibits the programmed ventricular output. In this manner, effective ventricular tracking of the atrial signal is assured; as the atrial rate increases so can the ventricular rate.

**Endless loop tachycardia.** When a retrograde P wave is sensed by the atrial amplifier and retrograde conduction is stable, an endless loop tachycardia will ensue. To avoid this tachycardia, the postventricular atrial refractory interval can be increased beyond the patient’s maximal retrograde conduction time (11,12). During the atrial refractory interval, the amplifier is insensitive to electrical signals. The atrial refractory interval prevents the endless loop tachycardia and concurrently limits the interval between consecutive atrial signals that can be sensed. When the interval between consecutive atrial signals is less than the sum of the pulse generator’s programmed AV interval and the post-ventricular atrial refractory interval, ventricular tracking does not occur. Thus, the upper rate limit must be sacrificed to avoid endless loop tachycardia.

### Table 1. Electrophysiologic and Ambulatory Electrocardiographic Data

<table>
<thead>
<tr>
<th>Case</th>
<th>Diag.</th>
<th>P Wave Amplitude (mV)</th>
<th>Min. VA Conduction Time (ms)</th>
<th>HR Prod. VA Block (beats/min)</th>
<th>Device</th>
<th>URL (beats/min)</th>
<th>ARI (ms)</th>
<th>Atrial Sensitivity (mV)</th>
<th>Study Dura. (h/min)</th>
<th>No. of Beats</th>
<th>Atrial Undersensing No. of Episodes</th>
<th>No. of ELTs</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>SB</td>
<td>3.0</td>
<td>215</td>
<td>140</td>
<td>925</td>
<td>80</td>
<td>100</td>
<td>0.75</td>
<td>22/30</td>
<td>74,649</td>
<td>—</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>2:1 AVB</td>
<td>4.2</td>
<td>335</td>
<td>140</td>
<td>501</td>
<td>107</td>
<td>200</td>
<td>1.8</td>
<td>22/57</td>
<td>71,387</td>
<td>—</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>CHB</td>
<td>2.3</td>
<td>200</td>
<td>160</td>
<td>501</td>
<td>90</td>
<td>60</td>
<td>3.2</td>
<td>25/42</td>
<td>79,832</td>
<td>—</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>2:1 AVB</td>
<td>7.4</td>
<td>230</td>
<td>140</td>
<td>925</td>
<td>90</td>
<td>100</td>
<td>1.0</td>
<td>8/11</td>
<td>35,759</td>
<td>—</td>
<td>169</td>
</tr>
<tr>
<td>5</td>
<td>2:1 AVB</td>
<td>6.0</td>
<td>320</td>
<td>140</td>
<td>925</td>
<td>115</td>
<td>100</td>
<td>1.5</td>
<td>22/44</td>
<td>105,253</td>
<td>—</td>
<td>143</td>
</tr>
</tbody>
</table>

Ante = anterograde; ARI = atrial refractory interval; CHB = complete heart block; Diag. = diagnosis; Dura. = duration; ELTs = endless loop tachycardias; HR Prod. = heart rate producing; Min. = minimal; Retro = retrograde; SB = sinus bradycardia; 2:1 AVB = second degree heart block; URL = upper rate limit; VA = ventriculoatrial.
Selective atrial sensing. Previous investigations in our laboratory have demonstrated that anterograde P waves can be distinguished from retrograde P waves. The mean amplitude of anterograde P waves generally exceeds that of retrograde P waves. The ratio of the amplitude of the anterograde atrial electrogram to that of the corresponding retrograde electrogram is approximately 1.25 to 1. Three-fourths of all anterograde P waves are at least 0.5 mV larger than their corresponding retrograde P wave (5). By selectively sensing anterograde atrial signals and ignoring retrograde signals, it is possible to eliminate endless loop tachycardia.

The majority of commercially available dual chamber pulse generators have fewer than five atrial amplitude sensitivity selections. These pacemakers and their corresponding sensitivity settings are listed in Table 2. Two investigational units, the CPI 925 and the CCS 501, have an extended range of atrial amplitude sensitivity settings. With their extensive selection of atrial amplitude sensitivity settings, these units can potentially discriminate larger anterograde atrial signals from smaller amplitude retrograde signals.

Elimination of endless loop tachycardia. To demonstrate that discriminating atrial sensing can abolish endless loop tachycardia, we studied five consecutive patients who had anterograde atrial signals that were at least 1.4 times larger than the corresponding retrograde signals and had an investigational device with multiple atrial amplitude sensitivity settings implanted. Sequential Holter monitoring demonstrated that with a high atrial sensitivity setting all patients sustained endless loop tachycardia and that when the atrial sensitivity was decreased, endless loop tachycardia was eliminated. The lower atrial sensitivity resulted in only sporadic atrial undersensing and in no instance did this produce atrial arrhythmias.

While selective atrial sensing is a promising method of eliminating endless loop tachycardia, it should be utilized only after careful patient evaluation. This technique should only be employed in those patients whose atrial sensing threshold is stable, as the amplitude of the atrial signal may vary (9). The ratio of the amplitude of anterograde-retrograde signals should be large and the pulse generator's sensing amplifier should be capable of discerning the difference in amplitude.

Clinical implications. Atrial signals having different amplitudes can be selectively sensed. Consequently, in patients with quantitatively distinct atrial electrograms who have an implanted pulse generator that has multiple amplitude sensing values, the pulse generator can be programmed to sense the anterograde atrial signals and ignore the ret-

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Atrial Settings (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotronik</td>
<td>102</td>
<td>0.7, 1.3</td>
</tr>
<tr>
<td></td>
<td>124A*</td>
<td>0.6, 1.2, 2.0</td>
</tr>
<tr>
<td></td>
<td>148A*</td>
<td>0.6, 1.2, 2.0</td>
</tr>
<tr>
<td>Cardiac Control Systems</td>
<td>501*</td>
<td>0.5, 1.0, 1.8, 2.4, 2.8, 3.2, 3.4, 4.5, 5.5, 6.4, 9.0, 11.0, 13.0, 18.0, 25.0 (low/high passband)</td>
</tr>
<tr>
<td>Cardiac Pacemakers, Inc.</td>
<td>925*</td>
<td>0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10, 11, 12, 13, 14, 15</td>
</tr>
<tr>
<td>Cordis</td>
<td>233F</td>
<td>0.5, 1.3, 2.5</td>
</tr>
<tr>
<td></td>
<td>415A</td>
<td>0.5, 1.3, 2.5</td>
</tr>
<tr>
<td>Intermedics</td>
<td>283-01</td>
<td>0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8</td>
</tr>
<tr>
<td>Medtronic</td>
<td>7005</td>
<td>0.6, 1.25, 2.5</td>
</tr>
<tr>
<td></td>
<td>7006</td>
<td>0.6, 1.25, 2.5</td>
</tr>
<tr>
<td>Pacesetter</td>
<td>283</td>
<td>0.5, 0.6, 0.8, 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 9.0, 11, 14</td>
</tr>
<tr>
<td>Siemens-Elema</td>
<td>674*</td>
<td>VHI, HI, LOW, VLO</td>
</tr>
<tr>
<td>Teletronics</td>
<td>2251</td>
<td>0.5, 1.0</td>
</tr>
<tr>
<td></td>
<td>2291</td>
<td>0.5, 1.0</td>
</tr>
<tr>
<td></td>
<td>6230*</td>
<td>0.6, 0.8, 1.0, 1.8</td>
</tr>
</tbody>
</table>

*In clinical evaluation.
rograde signals. In this manner, sensing of anterograde atrial
signals is ensured and endless loop tachycardia is elimi-
nated. With the elimination of endless loop tachycardia, the
atrial refractory interval can be shortened and the upper rate
limit can be independently programmed to be coincident
with the individual’s sinus rate during maximal exertion.
Atrial synchronous rate-responsive pacing can be main-
tained in the presence of sustained retrograde conduction.
When selective atrial sensing is employed to eliminate end-
less loop tachycardia, the stability of the atrial sensing should
be frequently evaluated, because the amplitude of the atrial
signals may fluctuate (9).

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