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Intermittent inhibition of biventricular pacing in a cardiac resynchronization therapy defibrillator

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Keywords

Biventricular pacing; Heart failure; Ventricular tachycardia

Case summary

A 55-year-old man with nonischemic cardiomyopathy (left ventricular ejection fraction 0.25), New York Heart Association class III heart failure, nonspecific intraventricular conduction delay (QRS duration 130 ms), frequent ventricular ectopy, and recent implantation of a Boston Scientific CONTAK RENEWAL 3 HE H177 cardiac resynchronization therapy (CRT) defibrillator presented to the clinic with persistent heart failure symptoms and only 50% biventricular pacing. Programmed parameters were as follows: mode: DDDR; lower rate: 70 ppm; upper rate: 160 ppm; paced atrioventricular (AV) delay: 190 ms; sensed AV offset: –50 ms; left ventricular (LV) pacing offset: –40 ms; postventricular atrial refractory period (PVARP): dynamic (170–250 ms); and rate smoothing: up 3%, down off.

Device telemetry (Figure 1) demonstrated sinus rhythm with occasional premature ventricular contractions (PVCs) and intermittent biventricular pacing (beats 3 and 12 only). Programmed AV delay should yield pacing of the LV 100 ms following an atrial sensed event because paced AV delay + sensed AV offset + LV pacing offset = 100 ms.

Upon examination of both atrial and ventricular sensed electrograms, it is apparent that the device did not track a number of normal sinus beats (outside of the PVARP) with biventricular pacing even though more than 100 ms had elapsed between atrial and ventricular sensing (beats 1, 6, 7, 8, and 11). In addition, for the one of the two beats with atrial sensing and biventricular pacing on this strip (beat 12), LV pacing occurs a little later than 100 ms following atrial sensing. Why was the device not biventricular pacing for these beats at the programmed AV interval?

Commentary

Conditions that may interfere with biventricular pacing include suboptimal programming of AV and interventricular timing, inhibition of pacing by ventricular ectopy, oversensing of far-field atrial depolarization,¹ any inappropriate programming that prolongs AV delay, such as AV search hysteresis (not available in this device), rate smoothing, PVARP, and sensitivity settings that result in T-wave oversensing. Based on review of the electrograms, there is no oversensing on the ventricular channel. Also, ventricular ectopy does not explain the failure to pace on the specified beats (1, 6, 7, 8, and 11). Furthermore, only for beats 5 and 10 was atrial sensing in the PVARP. The only remaining explanation is the way rate smoothing was programmed in this device.

Rate smoothing algorithms are used to regularize the ventricular response in patients with irregular heart rhythms such as atrial fibrillation,² 2:1 AV block or Wenckebach-type heart block,³ and frequent ventricular ectopy. Rate smoothing has also been reported to prevent torsades de pointes in patients with long QT syndrome.⁴ In this particular patient, rate smoothing had been previously programmed in order to provide a more consistent ventricular rate with his frequent ventricular ectopy.

The algorithm had been programmed to allow 3% upward but no downward rate smoothing. With this programming and the specific rate smoothing algorithm in this device, the interval of time from the previous right ventricular electrogram during which biventricular pacing is inhibited (upper rate smoothing, or URS window) is equal to 97% of the longest of the following three intervals: the previous R-R interval, the URS window for the previous interval, and the interval corresponding to the maximum tracking rate (375 ms). Calculations for the actual URS windows for each beat are listed in Table 1.

As shown in the annotated device strip in Figure 2 (boxes show duration of URS window), biventricular pacing does not occur for beats 1, 6, 7, 8, and 11 because ventricular sensing occurs before the URS window has ended for each of these beats. Of note, beats 4 and 9 are PVCs followed by atrial sensed events in the PVARP, followed by ventricular sensed events in beats 5 and 10. As a result, biventricular pacing does not occur for beats 5 and 10 for two reasons: inhibition by rate smoothing and atrial sensing in the PVARP. On beat 12, ventricular sensing has not occurred by the end of the URS window, so biventricular pacing occurs. Interestingly, the URS window ends more than 100 ms after atrial sensing, so the AV interval for this beat is longer than that for the other biventricular paced beat (no. 3). This would be expected because rate smoothing upward is similar to having an upper rate limit for that one particular cycle. As a result, upper rate behavior such as increased AV delays at slower rates is not uncommon with a very small or tight upward rate smoothing percentage.

This case highlights the potential undesirable effects of programming a small upper rate smoothing percentage in patients with biventricular pacing. The rate smoothing algorithm was subsequently programmed off in this patient. Of note, an alternative would have been to program a downward rate smoothing percentage of 3% while leaving upward rate smoothing off to help provide a more consistent ventricular rate in the setting of frequent ventricular

ectopy without compromising biventricular pacing. Upon device interrogation 1 month later, the patient was noted to have an increased percentage of biventricular pacing (83%, up from 50%), with some remaining inhibition by ventricular ectopy. His heart failure symptoms improved with the increased percentage of biventricular pacing resulting from the programming change.

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Abbreviations

AV	atrioventricular
BiVP	biventricular pacing
CRT	cardiac resynchronization therapy
LV	left ventricular
PVARP	postventricular atrial refractory period
PVC	premature ventricular contraction
PVP	PVARP after PVC
URS	upper rate smoothing

Figure 1.

Device interrogation tracing. Surface ECG lead, atrial electrograms, ventricular electrograms, and the marker channel are shown. Of the 12 beats, there are only two biventricular paced complexes (beats 3 and 12). The device makes no attempt to pace on sinus beats 1, 6, 7, 8, and 11 even though left ventricular pacing is programmed to occur 100 ms after atrial sensing and the actual AS-RVS intervals are longer than this. AS = atrial sensed event; BiVP = biventricular pacing; LVP = left ventricular paced event; LVS = left ventricular sensed event; PVC = premature ventricular contraction; RVP = right ventricular paced event; RVS = right ventricular sensed event.

Figure 2.

Review of device telemetry. An annotated version of the tracing from Figure 1 is shown. Each upper rate smoothing (URS) window starts at a ventricular sensed event with duration equal to 0.97 multiplied by the longest of the previous R-R interval, previous URS window, and interval corresponding to the maximum track rate. During the URS window, ventricular pacing cannot occur in response to an atrial sensed event (AS), explaining why there is no biventricular pacing for beats 1, 6, 7, 8, and 11. Beats 4–5 and 10–11 represent sequences with a premature ventricular contraction (PVC) followed by an AS in the postventricular atrial refractory period followed by a conducted ventricular beat. Biventricular pacing occurs in beats 3 and 12 because the URS window ends before ventricular sensing has occurred. Note that on beat 12, the interval between the AS and LVP/RVP is longer than the corresponding interval in beat 3 because the URS window persists longer after the AS. LVP = left ventricular paced event; LVS = left ventricular sensed event; RVP = right ventricular paced event; RVS = right ventricular sensed event.

Table 1
Determination of upper rate smoothing (URS) windows

Beat	Preceding R-R interval (ms)	Preceding URS window (ms)	Present URS window (ms)*
1	803	—	779
2	535	779	756
3	1120	756	1086
4	500	1,086	1,053
5	465	1,053	1,021
6	700	1,021	990
7	805	990	960
8	853	960	931
9	495	931	903
10	458	903	876
11	745	876	850
12	850	850	825

* Present URS window = 0.97 multiplied by the longest of the preceding R-R interval, the preceding URS window, or 375 ms (maximum tracking interval).