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Device rounds: T-wave oversensing: A cause of loss of cardiac resynchronization therapy

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ABSTRACT

A CRT-D patient presented with loss of biventricular pacing associated with heart failure symptoms. The electrocardiogram showed sinus rhythm with alternating wide unpaced and narrower paced QRS complexes. Device interrogation showed T-wave oversensing on all paced biventricular beats, with the following sinus P-wave not tracked due to it falling in the post-ventricular atrial refractory period, leading to intrinsic conduction. Device reprogramming from true bipolar (RV tip to RV ring) sensing to integrated bipolar (RV tip to RV coil) resolved the problem without having to decrease sensitivity values, allowing biventricular pacing close to 100% to resume with improvement of symptoms. T-wave oversensing is a frequently recognised cause of inappropriate therapy in implantable cardioverter defibrillators, but less frequently as a cause of loss of biventricular pacing in CRT-Ds. We review the different non-invasive strategies to overcome this problem.

1. Case report

A 78-year old patient was implanted with a biventricular defibrillator (Medtronic Viva Quad CRT-D with a 6935 Sprint Quattro Secure right ventricular lead and a 4298-88 quadripolar left ventricular lead) in 2014 for dilated non-ischemic cardiomyopathy with left ventricular ejection fraction (LVEF) of 25%, left bundle-branch block (LBBB) and New York Heart Association (NYHA) class II heart failure. Initial follow-up was unremarkable, with average percentage of biventricular (BiV) pacing of >97%, until December 2015 when a scheduled 6-month follow-up revealed a reduction in BiV pacing to 88%, associated with an increase in heart-failure symptoms. Device parameters are shown in Table 1. Interrogation of the device revealed a loss of BiV pacing of 12% due to ventricular sensed events (Vs) without any sustained arrhythmia. However, the electrocardiogram showed sinus rhythm with alternating wide unpaced and narrower paced QRS complexes (Fig. 1). Further device interrogation revealed excellent R-wave amplitude (>20mV) but with T-wave oversensing (TWOS, see Fig. 2) on all ventricular paced beats (BV), with the sensed T-waves at a coupling interval of 320 ms (188bpm) interpreted as ventricular events falling in the slow ventricular tachycardia (VT) zone (labelled TS). The sinus atrial beats following these TS events were not tracked due to them falling in the PVARP (AR), thus leading to intrinsic conducted beats (VS), corresponding to the wider QRS complexes on the surface ECG. Because the conducted QRS complexes fell outside the tachycardia detection zone, the VT counter was reset each time and no sustained arrhythmias were recorded. No major electrolyte disturbance or change in medication was found to explain the TWOS.

2. Discussion

This patient presented with heart failure symptoms due to loss of CRT pacing. The initial 6 lead ECG showed some unpaced QRS complexes, raising the differential diagnosis of intermittent atrial undersensing, loss of ventricular capture, or TWOS. However, alternating paced and unpaced cycles would be unusual in atrial undersensing and in ventricular non-capture (furthermore, pacing spikes would be expected in the latter setting). Device interrogation diagnosed TWOS.

The prerequisite for response to CRT is therapy delivery, if possible as close to 100% as possible [1]. The most frequent reasons for loss of CRT delivery are supra-ventricular arrhythmias, PVCs, intrinsic atrio-ventricular conduction (e.g. due to AV intervals being programmed too long, atrial undersensing, or sinus rate above the

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Table 1
Device parameters.

Bradycardia parameters	
Mode	DDD
Lower/upper rate	50/135
AV delay sensed/paced	100/130
Biventricular pacing	AdaptivCRT™ Bi-V and LV
Atrial lead	
Programmed output	2V @ 0.4 ms
Pace polarity	Bipolar
Programmed sensitivity	0.45mV
Sense polarity	Bipolar
PVARP	Auto (minimum 250 ms)
Right ventricular lead	
Programmed output	2V @ 0.4 ms
Pace polarity	Bipolar
Programmed sensitivity	0.45mV
Sense polarity	True bipolar (RV tip to RV ring)
Ventricular blanking post VP	230 ms
Ventricular blanking post VS	120 ms
Left ventricular lead	
Programmed output	3V @ 1 ms
Pace polarity	Extended bipolar (LV2 to RV coil)
Tachycardia parameters	
Slow VT zone	167-194bpm (NID 40 intervals)
Slow VT zone therapy	Off
Fast VT zone (via VF)	194-240bpm (30/40 intervals)
Fast VT zone therapy	Burst (x3), 35J (x5)
VF zone	>240bpm (30/40 intervals)
VF zone therapy	ATP during charge, 35J (x6)
T-wave oversensing algorithm	On

maximum tracking rate) and lead issues such increased left-ventricular thresholds [2]. Loss of CRT due to TWOS has been described in isolated case reports [3–8], and is more frequently associated with inappropriate shocks. This anomaly may be transient and not easy to identify without real-time EGMs or without recorded tachycardia episodes, although some devices record ventricular sensing episodes, which may provide useful clues for troubleshooting [2]. It is favored by low-amplitude R-waves or large T-waves e.g. in Brugada syndrome, hypertrophic cardiomyopathy, during exercise, hyperkalemia or with ventricular pacing. It can appear at any time during follow-up, and this is linked more to the dynamic nature of T-wave changes than to lead issues. Various algorithms exist to avoid TWOS, such as adjusting sensitivity adaptation (onset percentage and decay delay) as well as pattern recognition. The latter algorithm was activated in our patient's device, but was not useful as it is only implemented when tachycardia is detected, and serves to avoid inappropriate shocks (without avoiding TWOS *per se* and loss of CRT delivery). Of course, any type of ventricular oversensing may also raise the concern of bradycardia. Had our patient been pacemaker-dependent, TWOS would have lowered the ventricular rate to half the sinus rate, because of reset of the timing cycle and non-tracking of the following atrial event which falls in the PVARP.

The various programming options that may avoid TWOS are listed below as well as their impact in the patient described in the case.

1. *Decreasing ventricular sensitivity.*

TWOS only disappeared after decreasing the sensitivity from 0,45mV to 0,6mV, a setting that may be suboptimal due to the risk of undersensing ventricular fibrillation (VF).

2. *Modifying the programmed refractory periods.*

Increasing the ventricular refractory period (VRP) could be an option (the maximum programmable value for this device is 450 ms). However, in this instance, the PVARP would also have to

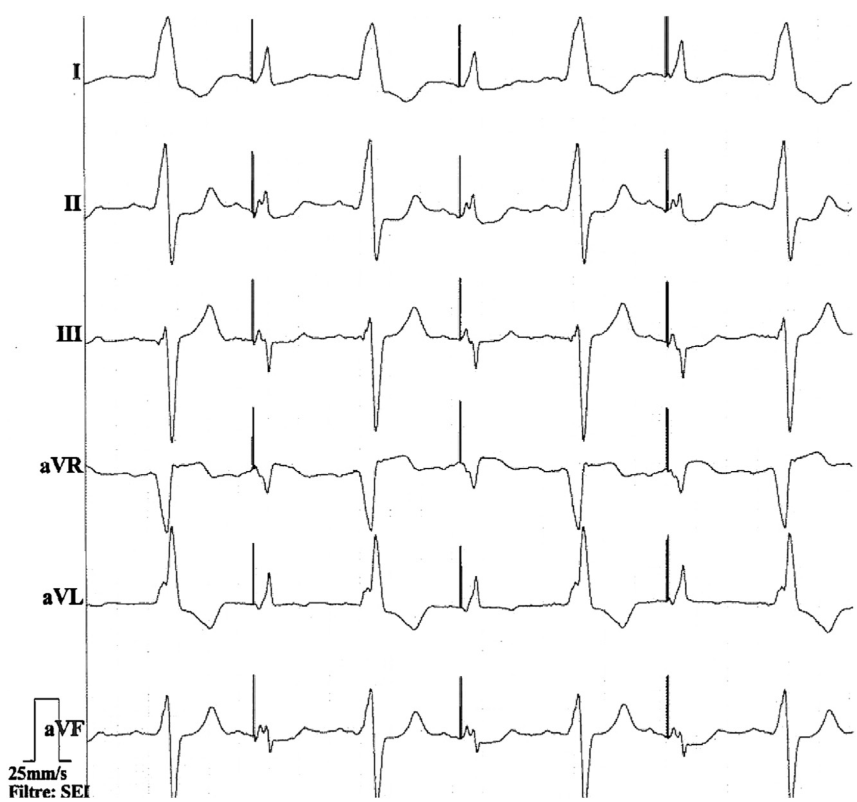

Fig. 1. ECG at 25mm/s, showing sinus rhythm with alternating wide intrinsic QRS complexes and narrower paced beats.

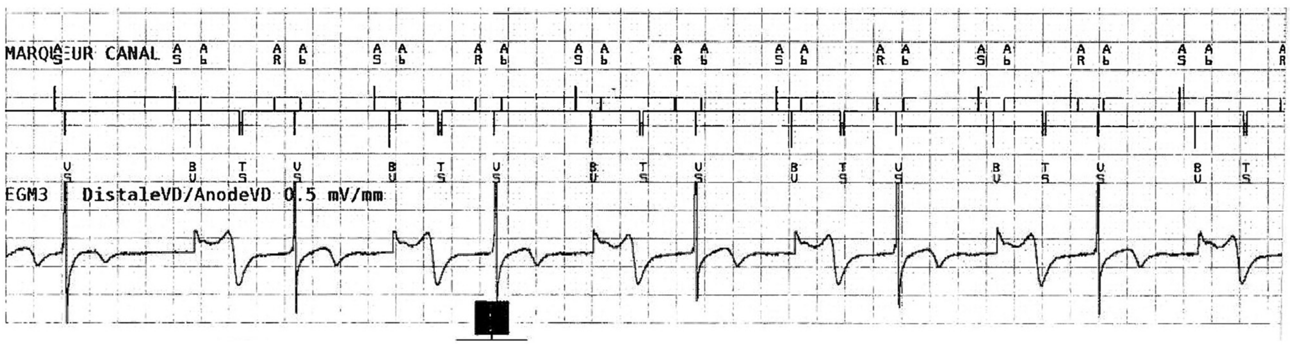

Fig. 2. Real-time tracing at 25mm/s, with T-wave oversensing on all paced beats (BV). The sensed T-waves fall in the slow ventricular tachycardia zone (TS) with the following sinus atrial beat falling in the PVARP (AR) and are not tracked, leading to spontaneous conduction (VS). Note the difference in EGM morphology of the T-waves between the paced and intrinsic beats.

be increased. The PVARP is always programmed longer than the VRP, in order to avoid that a blanked ventricular premature beat may result in far-field R-wave oversensing in the atrial channel, thus triggering an AV delay with ventricular pacing on the T-wave of the premature beat (which may be pro-arrhythmic). Unduly prolonging the PVARP will limit the upper tracking rate and prevent CRT delivery during exercise. The option of decreasing the PVARP (and inactivating the post-PVC PVARP extension) in order to avoid atrial refractory sensing of the sinus P-wave will not be helpful, as the upper tracking rate will not allow ventricular pacing before intrinsic AV conduction occurs.

3. *Adjusting the dynamic sensitivity parameters.*

In some ICDs (e.g. St-Jude Medical and Biotronik), TWOS can be eliminated by increasing the threshold start or by prolonging the decay delay. In Medtronic ICDs, the time before decay can only be increased by increasing the VRP as described in the previous point.

4. *Programming integrated bipolar sensing.*

When reprogramming the right ventricular (RV) detection from true bipolar (RV tip to RV ring) to integrated bipolar (RV tip to RV coil), TWOS disappeared at 0,3mV sensitivity and was only observed when the sensitivity level was programmed to 0.15mV, enabling 100% BiV pacing to resume (Fig. 3). This allowed us to keep the sensitivity at 0,45mV, without increasing the risk of undersensing VF. Resolving TWOS by programming an integrated bipolar sensing configuration has been previously described [9,10], but is currently only available in Medtronic devices. Integrated bipolar sensing may carry a small risk of diaphragmatic myopotential oversensing and of P-wave oversensing, both of which can be evaluated by carefully analysing the ventricular electrogram.

5. *Delivering univentricular LV or sequential BiV pacing.*

TWOS was only observed during simultaneous BiV pacing, and not during sensing of intrinsic conducted beats (Fig. 2). Therefore, delivery of fusion pacing (i.e. pacing of the LV and intrinsic conduction to the RV) would be helpful in this patient. This can be achieved in three ways:

a) Using the AdaptivCRT™ algorithm which automatically optimizes the AV delay every minute [11], and delivers univentricular LV pacing if the AV conduction is normal (AS-VS <200 ms and AP-VS <250 ms, with extension of these values by 20 ms for devices introduced as from 2016). Fusion pacing occurs as the AV delay is programmed at 70% of the intrinsic delay (or with an offset of 40 ms, whichever is shorter). A real-time electrogram showed no TWOS when the device was functioning with univentricular LV pacing (Fig. 4), even when sensitivity was programmed to 0,15mV. However, consistent univentricular LV pacing cannot be guaranteed, as the device will switch to BiV pacing in case of prolongation of the intrinsic AV delays, if the heart rate exceeds 100bpm, or if the patient has atrial fibrillation. In our patient, the AdaptivCRT™ algorithm *was active at the time of initial interrogation*, and the counters indicated that 88% of ventricular paced beats were delivered

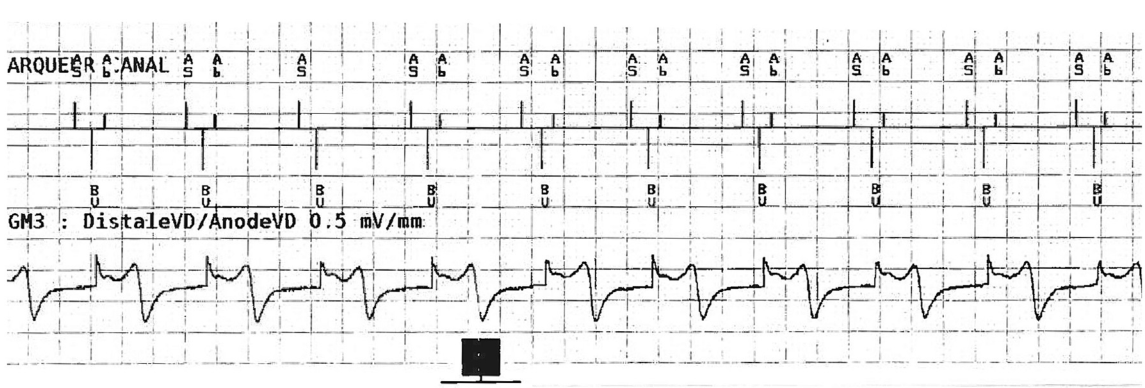

Fig. 3. Real-time tracing at 25mm/s, demonstrating biventricular pacing without T-wave oversensing at a sensitivity of 0,30mV in the integrated bipolar setting (the displayed ventricular electrogram is true bipolar, as the RV tip to RV coil electrogram cannot be displayed in this model).

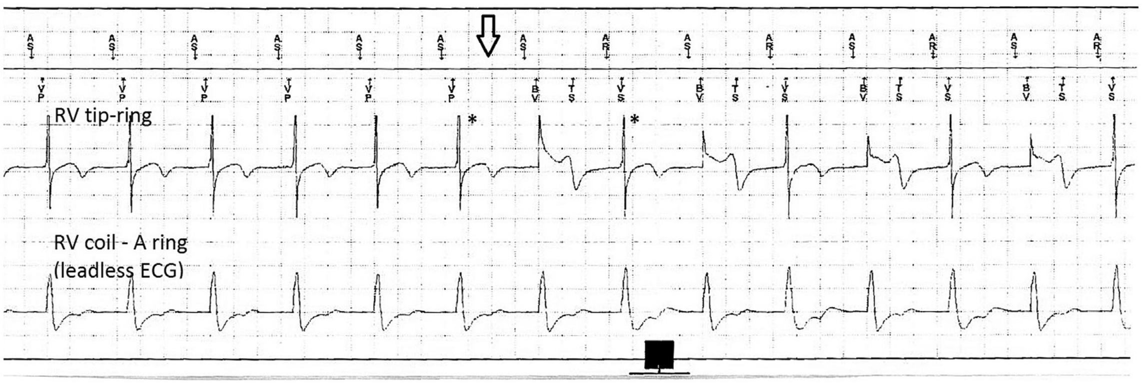

Fig. 4. Real-time tracing at 25mm/s demonstrating the switch in programming (7th beat) from LV-only pacing (VP) to biventricular pacing (BV) at a sensitivity setting of 0.15 mV in a true bipolar configuration. Note the appearance of T-wave oversensing during biventricular pacing (second half of strip, arrow), and the identical right ventricular EGM morphology during LV-only pacing and during ventricular sensing (asterisks), due to fusion pacing by the AdaptivCRT™ algorithm and preserved intrinsic conduction to the right ventricle.

with LV-only pacing (during which there was no TWOS). However, the remaining 12% beats were delivered with BiV pacing.

b) Programming univentricular LV pacing (i.e. inactivating RV pacing). However, the degree of fusion pacing will depend on the programmed AV delay and the intrinsic conduction delays, which vary over time. In case of a greater participation of LV capture (and less fusion), the right ventricular electrogram morphology may change. Therefore, absence of TWOS should be tested at different AV delays in this pacing configuration.

c) Sequential BiV pacing with LV pre-excitation may sufficiently alter the electrogram repolarization morphology, and may be tested at different VV delays. This strategy has previous been reported to eliminate TWOS in a CRT-D patient [3].

d) Programming a DDI(R) mode and activating the ventricular sense response algorithm. This algorithm delivers VVT pacing with triggered biventricular pacing in response to RV sensed events. This mode has the advantage of ensuring that RV capture (leading to TWOS in our patient) will not occur because RV pacing will fall in the physiological ventricular refractory period. However, it may result in a lesser degree of resynchronization (or even pseudofusion), especially if the patient does not have LBBB or if the QRS complex is not very wide [12]. In case TWOS persists despite the VVT mode, ventricular pacing will only be consistently delivered if the delay between the sensed T wave and the following R wave is longer than the programmed upper tracking rate interval, which was not the case in our patient.

In cases where reprogramming fails to solve the issue of TWOS, and especially if the R-wave amplitude is small (<4mV) more invasive options are often required, such as repositionning the lead or implanting a new pace-sense lead (this is not an option in case of DF-4 connectors). Switching the RV and LV leads in the generator ports has also been reported [13], but is only possible in case of DF-1 ICD leads and IS-1 LV leads.

In our patient, we opted for programming sensing to an integrated bipolar configuration with a sensitivity of 0.45mV, and maintaining the AdaptivCRT™ algorithm. Follow-up at 3 month revealed 97% CRT delivery, with a marked improvement in heart failure symptoms.

3. Conclusion

TWOS is probably underecognised as a cause of loss of CRT in heart failure patients. Thankfully, modern devices allow several different reprogramming options that can potentially resolve the issue without invasive measures. We describe the use of alternating sensing configuration and utility of univentricular LV pacing with the AdaptivCRT™ algorithm that successfully overcame TWOS without increasing the risk of arrhythmia underdetection.

Conflict of interests

N.D has no conflicts of interest to report; H.B. has received speaker fees from Biotronik, Boston Scientific, Medtronic and Sorin and institutional fellowship support/research grants from Biotronik, Boston Scientific, Medtronic, Sorin and St-Jude Medical.

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