CASE REPORT

Undersensing by an ICD Due to Alternans of the Ventricular Electrogram

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Alternans of the ventricular electrogram (VEGM) during ventricular tachycardia (VT) is a rare cause of ventricular undersensing by an implantable cardioverter-defibrillator (ICD). This report describes a patient with a St. Jude ICD who exhibited sustained monomorphic VT associated with surface QRS alternans, alternating cycle lengths, alternans of the VEGM causing intermittent undersensing of the smaller component, and intermittent 2:1 counting of ventricular intervals during 1:1 sensing in response to the ICD detection algorithm. VEGM undersensing was corrected noninvasively simply by programming the threshold start from 62.5% to 50% which increased the sensitivity based on the amplitude of the VEGM. This maneuver did not affect the satisfactory and stable defibrillation threshold.

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Alternans of the ventricular electrogram (VEGM) during ventricular tachycardia (VT) is a rare cause of ventricular undersensing by an implantable cardioverter-defibrillator (ICD).¹ We report a patient who exhibited sustained monomorphic VT associated with surface QRS alternans, alternating cycle lengths (CLs), alternans of the VEGM causing intermittent undersensing of the smaller component by the ICD, and intermittent 2:1 counting of ventricular intervals during 1:1 sensing in response to the ICD detection algorithm.

CASE REPORT

A 60-year-old man with a history of myocardial infarction (left ventricular ejection fraction 45%) and coronary artery bypass surgery, presented with sustained monomorphic VT in March 2009. A single chamber ICD (St. Jude Medical Current RF VR

1207–36; Sylmar, CA, USA) was implanted with a dual coil shock lead at the right ventricular apex. The defibrillation threshold (DFT) was 20 J. Ventricular fibrillation (VF) was induced and correctly sensed by the device at a sensitivity of 1 mV. The amplitude of the ventricular electrogram in sinus rhythm (R wave) was >12 mV at implantation. The device was programmed as follows: VVI mode (35 ppm), refractory period after sensing 125 ms (acting like a blanking period except that the device senses the amplitude of the VEGM during this interval), maximum sensitivity 0.3 mV, sensing threshold start at 62.5%, and decay delay at 60 ms (all nominal values). Detection zones were set as follows: VF zone for a CL <270 ms (36 J shocks), VT-2 zone for CL <300 ms (three attempts of antitachycardia pacing followed by 36 J shocks) and VT-1 zone (monitoring only) for CL <400 ms. There were no arrhythmias during the follow-up period and the R wave remained >12 mV.

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Figure 1. Ventricular tachycardia (VT) transmitted by remote monitoring. The ventricular electrogram (VEGM) is on top, marker channel in the middle, and measured intervals at the bottom. Panel A: VT with alternating cycle lengths (359/297 ms) and corresponding VEGM alternans showing a change in amplitude and morphology. There is intermittent undersensing of the smaller VEGM deflection by the ICD. The marker “-” indicates that normal sensing has occurred but the cycle was not binned for counting. Panel B: VT without cycle length alternans showing that intermittent undersensing of the smaller component of the VEGM persists. Panel C: Following detection of the VT-1 monitoring zone, VEGM undersensing by the ICD recurs but it is now on a 2:1 basis causing “return to sinus” annotation during ongoing VT. Paper speed is 25 mm/s.

In December 2011, the patient developed dizziness and remote monitoring documented several arrhythmia episodes interpreted as VT by the ICD. Figure 1 shows a tachycardia (subsequently proven to be VT) with alternating CLs associated with alternating configuration and amplitude of the VEGM. During VT there was intermittent undersensing of the smaller intracardiac electrograms at times producing undersensing of alternate beats. The ICD also displayed periods of 2:1

counting of ventricular intervals during 1:1 sensing (Fig. 2).

An electrophysiologic study, with simultaneous wireless recordings from the ICD, revealed inducible monomorphic VT with a stable CL of 350 ms and surface QRS alternans (Fig. 3A). There was AV dissociation and no His bundle potential preceding ventricular activation (Fig. 3B). During monomorphic VT, the VEGM recorded by the ICD clearly showed alternans with intermittent

Figure 2. 2:1 ICD counting. The ventricular electrogram (VEGM) is on top, marker channel in the middle, and measured intervals at the bottom. There is VEGM and cycle length alternans. The symbol “-” indicates that the cycle or beat is sensed by the ICD but not used for counting. This occurs because of the mathematical effect of alternating cycle lengths on the average interval required for counting by the ICD algorithm. See text for details. Paper speed is 25 mm/s.

undersensing (Fig. 4). VT was successfully terminated by antitachycardia pacing in the right ventricular apex.

The ventricular sensing threshold start was reprogrammed from 62.5% to 50% with unchanged decay delay of 60 ms and other parameters.^{2,3} At reinduction of the VT, all complexes were sensed during VEGM alternans. After reprogramming, the DFT was 17.5 J and VF was normally sensed at a sensitivity of 1 mV. All the parameters of the ICD were left unchanged except for the threshold start.

DISCUSSION

Alternans of the surface QRS complex in VT is not uncommon.^{4–6} Kremers et al.⁴ reported a similar incidence of surface QRS alternans (defined as ≥ 0.1 mV) in supraventricular tachycardia compared to VT (27–30%), best seen in leads V2 and V3. However, surface QRS alternans in VT is rarely associated with alternans of CL or VEGM.^{1,7,8}

CL Alternans

The combination of surface QRS alternans and alternating CLs has been reported in only two cases of VT both “idiopathic” in origin (80 ms and variable from 20 to 55 ms).^{7,8} One patient underwent catheter ablation and the other received antiarrhythmic drug therapy. Maury et al.⁹ reported al-

ternating duration of the stored ventricular electrograms (10–20 ms) in 6 of 111 episodes of monomorphic VT in an ICD population of 25 patients. Thus, visible CL variation (>20 ms) in the surface ECG is rare in monomorphic VT.

Ventricular Electrogram Alternans

Jongnarangsin and Mela¹ reported the occurrence of VEGM alternans in a patient during ICD replacement. With a device sensitivity of 0.27 mV, fast VT (CL 185 ms) was induced by a T wave shock. The VEGM demonstrated dramatic alternation of the R wave amplitude resulting in device sensing of only every other beat. After a 9 second delay the VT degenerated into polymorphic VT/VF with less variation in the VEGM amplitude. In this circumstance, the presence of corresponding surface QRS alternans was not obtainable. Repeat testing at a device sensitivity of 0.18 mV reproduced the same sequence of events. Undersensing was corrected by the implantation of a separate ventricular pacing/sensing lead.

Maury et al.⁹ studied the VEGM of 111 episodes of monomorphic VT retrieved from 25 ICD patients. Using a complex computer program and spectral analysis, they found VEGM alternans in 23 of the VT episodes (20%) in 36% of the patients. VEGM alternans was visually discernible in only one patient.

Figure 3. (A) 12-lead surface ECG during monomorphic ventricular tachycardia (VT) at cycle length of 350 ms. Surface QRS alternans (≥ 0.1 mV) is clearly seen in leads V₃ and V₄. Paper speed is 25 mm/s. (B) Surface lead V₃ and intracardiac recordings during monomorphic VT at cycle length of 350 ms. There is AV dissociation and disappearance of the His bundle deflection previously present during stable sinus rhythm. HRA d = high right atrium, HIS d = His bundle area, CS 9–10 = proximal coronary sinus, RVA d = right ventricular apex. All intracardiac ventricular recordings are monomorphic. Paper speed is 100 mm/s.

Figure 4. Wireless recording by the ICD during induced monomorphic ventricular tachycardia (VT). The surface ECG is on top and the ventricular electrogram (VEGM) is below the ECG. The VEGM shows alternans. The marker channel (third channel) shows intermittent undersensing of smaller intracardiac complexes. The bottom channel is the leadless ECG. Paper speed is 25 mm/s.

Counting

The unusual occurrence of 2:1 counting by the device during 1:1 sensing is related to the binning system of St. Jude ICDs. An ICD uses a combination of the instantaneous ventricular interval and the interval average (the average of the instantaneous interval and the three previous intervals) to classify, or "bin" each beat or interval.¹⁰ When the instantaneous interval and interval average agree (i.e., both fall into the sinus, Tach A, Tach B, or Fibrillation zone), the interval or beat is binned accordingly. When the interval falls into a Tach zone, but the interval average falls into the sinus zone, or vice versa, the interval is considered a "trashed" beat, and is not binned or counted at all. A discarded interval does not affect the existing bin count in any way. In essence, it is as if the discarded beat or interval had never existed. In our patient, CL alternation created 2:1 counting as a result of the mathematics of the counting algorithm and the critical duration of the intervals presented to the ICD. The discarded intervals are not labeled with a marker symbol but as shown in Figure 2 with the marker "-." The marker confirms normal sensing of the beat in question.

TREATMENT

VEGM undersensing was corrected noninvasively only by programming the threshold start from 62.5% to 50% which increased the sensitivity based on the amplitude of the VEGM.³ The ICD measures the peak amplitude of the VEGM in the refractory period (as above) initiated by sensing. The threshold start calculates a percentage of the peak VEGM amplitude to provide a dynamic sensitivity function. After the decay delay, the threshold start begins the linear decrease in the gain until it reaches maximum sensitivity.³ The decrease in the threshold start in this case contrasts with the increase in the percentage of the same parameter used to treat oversensing by decreasing sensitivity.

Mechanism of Alternans

The precise mechanism of VT alternans remains unknown. There may be fusion by two depolarization wavefronts with different velocities, 2:1 lack of depolarization of a small portion of the ventricles on every other beat leading to changes of activation, or alteration (decremental conduction) in an

exit pathway of a reentry circuit or two discrete exit sites.^{11,12}

CONCLUSION

Our patient exhibited surface QRS alternans, obvious alternating CLs and alternans of the VEGM associated with undersensing of the smaller component. In addition there was 2:1 counting of the ventricular intervals during 1:1 sensing of VT related to the mathematical behavior of the St. Jude ICD sensing algorithm and the critical duration of the alternating ventricular interval. Normal sensing of the VEGM during alternans was restored by programming a parameter that increased ventricular sensitivity.

Glossary of Abbreviations

VEGM:	Ventricular Electrogram
VT:	Ventricular Tachycardia
ICD:	Implantable Cardioverter-Defibrillator
DFT:	Defibrillation Threshold
VF:	Ventricular Fibrillation
CL:	Cycle Length

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