Repeat inappropriate defibrillator discharges following defibrillator implantation. What is the mechanism and treatment?

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Introduction

Inappropriate shocks from implantable cardioverter-defibrillator (ICD) devices are a well-described clinical problem that contributes to patient morbidity and mortality. There are a number of causes for inappropriate ICD discharge, and T-wave oversensing (TWOS) is one such example. Improvements in ICD sensing algorithms have reduced the incidence of inappropriate therapies but have not eliminated this clinical problem. In this article we present an unusual cause of TWOS leading to multiple inappropriate ICD discharges. Furthermore, we review the algorithms in use by the major device manufacturers to help reduce the incidence of TWOS.

Case report

A 51-year-old man with a history of nonischemic cardiomyopathy, paroxysmal atrial fibrillation, and intermittent complete heart block had previously undergone dual-chamber pacemaker implantation. He underwent upgrade to a CRT-D device for progressive worsening left ventricular dysfunction, which was presumed related to a pacing-induced cardiomyopathy. A Medtronic Viva Quad XT CRT-D (Model DTBA1Q1, Medtronic, Minneapolis, MN) device was implanted without complication. The device was programmed with a single ventricular fibrillation (VF) zone of 300 msec.

While exercising shortly after device implantation, the patient developed atrial fibrillation with rapid ventricular response with ventricular rates in the VF zone, resulting in an inappropriate shock. The initial defibrillation restored sinus rhythm with ventricular rates below the VF zone (Figure 1). Despite having the T-wave oversensing algorithm (TWave) turned on, the patient received 4 additional defibrillations. An example of the intracardiacs during the second through fifth defibrillation is seen in Figure 2. The device lead parameters were all unchanged from implant.

Why did this patient receive 4 additional defibrillations despite being in sinus rhythm with rates below the VF zone?

Discussion

Careful review of the rate histogram in Figure 1 shows that following the initial shock, the patient converts to sinus tachycardia at a cycle length of approximately 450 msec. While the patient is in sinus rhythm 2 populations of V-V intervals with cycle lengths ranging between 120 and 280 msec are evident (arrows on Figure 1). This finding has been described as a "train track line or railroad pattern" and is a consequence of double-counting, resulting in T waves being sensed as additional R waves.[1] As a result, TWOS causes corresponding V-V intervals to be incorrectly sensed within the VF detection zone (300 msec). The patient's device responds accordingly, delivering the second through fifth inappropriate discharge.

TWOS is a well-known complication of implantable defibrillators.[2] Proper ICD function requires a delicate balance in sensing requirements, which is a technically challenging feature for ICD program designers. ICD sensing thresholds must be sensitive enough to detect the low-amplitude, high-frequency signals that occur during ventricular fibrillation while concomitantly excluding entities such as T wave signals or electrical noise.[3] Multiple current methods exist to help prevent TWOS (Table 1). The device in our patient uses TWave Discrimination, a proprietary algorithm that uses differential frequency between the R waves and T waves. Over the course of 6 ventricular events the device measures the largest 3 R waves, creates an average, and uses this as a threshold, below which the device

KEY TEACHING POINTS

- Despite modern T-wave oversensing (TWOS) prevention algorithms, TWOS remains an important clinical issue for physicians following patients with defibrillators.

- The TWave discrimination algorithm failed to prevent inappropriate shocks owing to late sensed T waves and, potentially, variation in the R-wave and T-wave amplitude post shock.

- Clinicians who follow defibrillators with TWOS need to be aware of this algorithm and should consider lengthening the redetect intervals to allow the algorithm more time to make a new template post therapy.

classifies the event as a T wave.[4] In our patient, this TWave algorithm fails for a combination of 3 reasons. First, the TWave algorithm does not "bin" sensed events <140 milliseconds, even if they meet T-wave frequency criteria as T waves, in order to avoid oversensing nonphysiologic events as T waves.[5] Our patient senses the T wave late in the true R-R interval, just before the next R wave, resulting in a short (140 msec or less) pseudo-"R-R" interval. In addition to the late sensed T waves being "binned" as R waves, post shock there may be R-wave and T-wave amplitude and frequency variation, causing the auto-adjusting TWave alogorithm to develop a new template, which also may contribute to inappropriate R-wave and T-wave classifica-

tion.[1] Coupled with the short but nominal redetect with 12 of 16 events (which was programmed in our patient), this does not provide the TWave algorithm enough data following defibrillation to appropriately discriminate between the R and T waves. Consequently, the TWave algorithm failed to reject TWOS, which resulted in the 4 additional inappropriate shocks in our patient, once sinus rhythm was restored. The event terminated owing to slowing sinus rate after the patient stopped exercise, resulting in longer R-R intervals and, presumably, more stability in the R-wave and T-wave amplitude and frequency post shock.

At follow-up, the patient underwent standard reprogramming measures in an attempt to prevent further events due to TWOS, but the patient ultimately underwent ventricular lead revision, which helped resolve the TWOS. No additional shocks or TWOS have occurred in the year since lead revision.

To our knowledge, this is the first case of TWOS resulting from late sensed T waves coupled with nominal redetection times despite using the TWave discrimination algorithm. This highlights the limitations of the current TWave discrimination algorithm, which can lead to a failure to protect against inappropriate therapies. In this case, the TWave detection algorithm failed to work appropriately because of late sensed T waves, potential variations in R-wave and T-wave amplitude and frequency, and short redetect intervals, which are nominally programmed on ICDs. Clinicians who follow defibrillators with TWOS need to be aware of this algorithm and should consider lengthening the redetect intervals to allow the algorithm more time to make a new template post therapy.
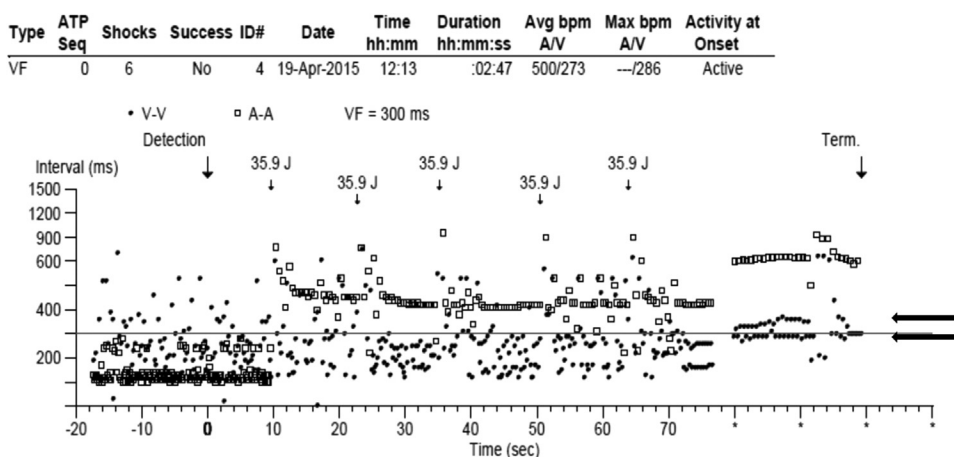

Figure 1   Rate histogram from the first through fifth shock. The patient was initially in atrial fibrillation, and the first defibrillation restored sinus rhythm. After the first shock, there are at least 2 different populations of "R" waves seen representing T-wave oversensing. The arrows at the conclusion of the slide show the classic "train tracking" seen in T-wave oversensing.
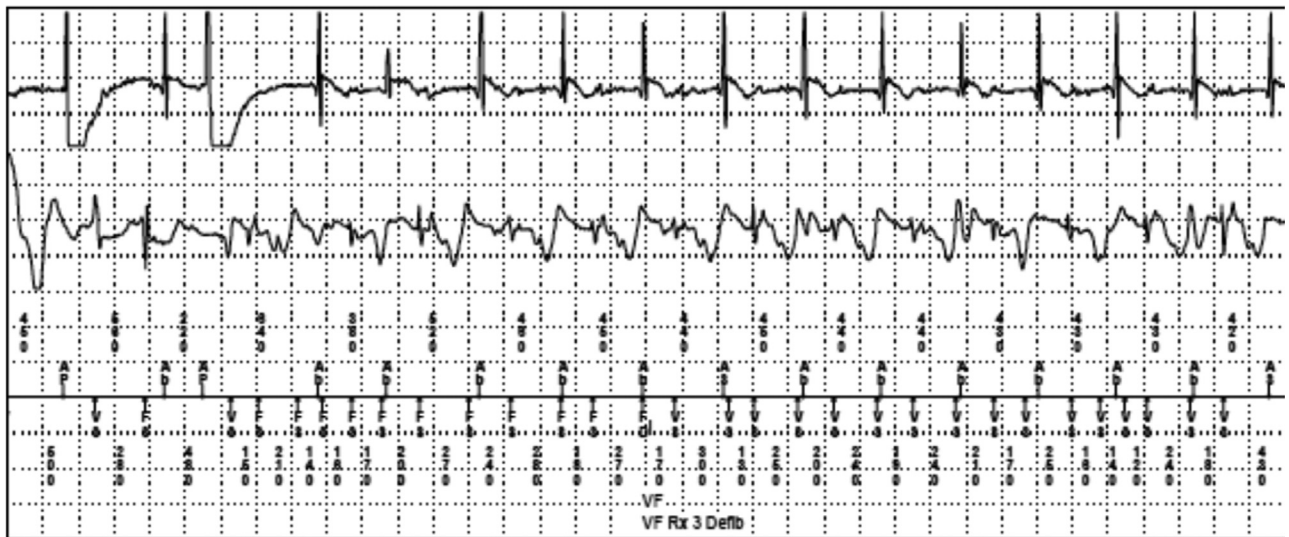
Figure 2 A representative sample of the intracardiacs during the second through fifth defibrillation. During the nominal redetection time, the oversensed T waves are sensed late in the pseudo-"R-R" interval. The TWave algorithm does not classify these short coupled pseudo-"R-R" intervals as T waves, resulting in inappropriate T-wave oversensing. This failure of the TWave algorithm, coupled with the nominal (12 of 16) redetection times, resulted in the inappropriate shocks.

Table 1 Methods for prevention of T-wave oversensing

Manufacturer	Program Name	TWOS Algorithm	Programmable
Biotronik	Enhanced T-wave suppression (TWS)[6]	With enhanced T-wave suppression algorithm enabled, high pass filtering is increased in order to reduce detection of low-frequency T waves. Additionally, the upper threshold for R-wave detection is increased to 75% of the previously measured R wave.	Yes
Boston Scientific	Not applicable[7]	Boston Scientific Cognis and Teligen defibrillators avoid TWOS through a narrow-frequency Band Pass filter, which detects R wave signals in the range of 20–85 Hz. Low-frequency T waves are typically below this detection window, and are excluded.	No
Medtronic	TWave[4]	Avoids TWOS through the application of a differential frequency filter, which amplifies the R wave signal, as compared to the T wave signal. Additional rate and pattern criteria are applied to confirm T-wave detection	Yes
St Jude Medical	SenseAbility[8]	Reduces TWOS by tailoring post-R-wave adjustable sensitivity using the St Jude Medical SenseAbility proprietary algorithm. In addition, St Jude programming provides a low-frequency attenuation filter to exclude T wave signals.	Yes

TWOS = T-wave oversensing.

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