A 'shocking' case rectified

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Device rounds:

A ‘shocking’ case rectified

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Key words: implantable cardioverter defibrillator; inappropriate shock; ventricular oversensing; T wave oversensing; rectification
**CLINICAL PROBLEM**

A 29-year-old man received in 2008 an implantable cardioverter defibrillator (ICD) Lumax VR-T 340 XL connected to a Linox S 65 single coil true bipolar shock lead (Biotronik SE & CO, KG, Berlin, Germany) after successful resuscitation from sustained ventricular tachycardia (VT). An underlying Brugada syndrome (BS) was diagnosed. At implant R wave sensing was 12.5 mV. Tachycardia detection was programmed as follows: VT monitoring zone between 180 and 240 bpm and ventricular fibrillation (VF) zone for rates above 240 bpm. VF induction was performed and showed correct sensing at least sensitivity. The patient remained asymptomatic until November 2012 when he experienced an ICD shock during strenuous exercise (fig. 1). Is this an appropriate or inappropriate shock and what is the cause of the shock?

**COMMENTARY**

Looking at the ventricular intracardiac electrogram (VEGM) and the farfield electrogram (FF) in fig. 1, there is a regular rhythm with cycle length (CL) of 420 ms. The channel with the marker annotations (M) reveals intermittent oversensing, coinciding with the T waves, strongly suggesting T wave oversensing (TWOS). R wave double counting and noise oversensing can be excluded based on the morphology of the VEGM and the marker positions. Hence, the patient experienced an inappropriate shock due to TWOS during exercise related sinus tachycardia.

**CAUSES OF T WAVE OVERSENSING**

TWOS is a common cause of inappropriate shocks and may occur in up to 2% of ICD patients. It can be caused either by diminished R waves or by enlarged T waves. Shrinkage of R waves may be caused by microdislodgement of the lead, localized fibrosis at the lead tip-tissue interface or by any underlying disease causing fibrosis. On the other hand, possible reversible causes of enlarged T waves are ischemia, pulmonary embolism, metabolic disorders such as hyperglycemia, electrolyte disturbances, QT prolongation and intoxication. All these causes could be excluded in our patient. However, BS is characterized by spatial and temporal heterogeneity of repolarization, leading to variations in T wave amplitude and increased risk of TWOS.
All ICD manufacturers are using a variable sensitivity to prevent T wave sensing without impairing R wave sensing. Sensitivity is least at the moment of R wave sensing. After a given delay sensitivity is gradually increased in a time-dependent manner till maximum sensitivity is reached. In all Biotronik Lumax devices automatic sensitivity control (ASC) is based on an upper (UT) and lower threshold (LT). The UT at 50% of the R wave amplitude is held for 360 ms after a sensed event (hold-off period). This hold-off period is used to prevent TWOS. Then sensitivity is increased to 25% of the R wave amplitude (LT), to allow detection of small electrograms as in VF. It is extremely important to obtain R waves as large as possible during implant, especially in BS, to prevent TWOS.

**SOLUTIONS**

TWOS may be solved by invasive or non-invasive measures. Lead repositioning or generator change are both invasive procedures that may be required, but are prone to serious adverse events such as device infection. Therefore, solving TWOS by non-invasive means is highly preferable. First, ventricular sensitivity may be decreased. This may however lead to undersensing and should always be followed by VF induction to confirm correct VF detection. In Biotronik Lumax devices it is also possible to separately program the UT, the hold-off period and the LT. Secondly, the high pass filter may suppress lower frequency signals (T waves) without compromising R wave amplitude. Biotronik Lumax devices have a T wave suppression mode, where the UT is at 75% of the R wave amplitude and the high pass filter is set to 20 Hz instead of 10 Hz. While this mode may eliminate TWOS it can also result in undersensing of VF, as was the case in our patient. A third option available in Biotronik Lumax devices (300 & 500 series) is signal rectification. Four modes are available: full, positive, negative and AUTO. Rectification ensures that all cardiac signals are sensed appropriately (fig. 2). Full wave rectification is the nominal setting and “flips” wave forms from negative to positive allowing detection of both positive and negative signals. The options “negative” and “positive” rectification are based on a two-step signal processing. First, half wave rectification enables detection of exclusively positive half waves, ignoring negative half waves. Secondly, signal inversion can eliminate TWOS as it facilitates sensing if the largest signal has a negative deflection and inverts giant T-waves into the negative domain. AUTO rectification uses half wave rectification and automatically
inverts the signal on a beat to beat basis depending on the maximum amplitude. In devices from other manufacturers only full wave rectification is used.

In our patient a bicycle stress test was performed to modify signal rectification in order to eliminate TWOS. During this test the programmer wand was taped to the patient’s ICD pocket. Thereby all therapies and arrhythmia detection are automatically turned off, while real time VEGM recording and marker setting remain active. TWOS occurred at a CL of 380ms, while the device was still programmed at negative rectification. Switching to positive rectification immediately eliminated TWOS as illustrated by the channel with the marker annotations (fig. 3). The VEGM morphology was inverted resulting in a larger positive R wave and a more prominent negative T wave. As R wave measurement was 18 mV after the rectification change and sensitivity was not altered, VF was not reinduced. Afterwards the patient remained asymptomatic, while repeatedly performing vigorous exercise. No further recurrences of TWOS have been observed during both clinical follow-up and telemonitoring.

15 CONCLUSION

TWOS is a common cause of inappropriate ICD therapy. Non-invasive reprogramming of sensing behavior, including signal rectification in Biotronik Lumax devices effectively allows prevention of TWOS on a patient tailored basis and may avoid inappropriate shocks and unnecessary invasive procedures.

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REFERENCES


LEGEND TO FIGURES

FIGURE 1
Rhythm strip from the ICD showing the recorded event during exercise. The upper tracing shows the channel with the marker annotations (M), the second tracing is the farfield channel from the ICD (FF) and the lower tracing is the ventricular intracardiac electrogram (VEGM). After reaching the VF detection criteria (12 in 16 intervals with CL < 250 ms), the device charges and a 40 joules shock is delivered.

FIGURE 2
Rectification and signal inversion. Four options can be programmed: full, positive, negative and AUTO. When using full rectification the negative spikes of the incoming signal will be flipped to the positive domain, allowing detection of both negative and positive signals. When programming either positive or negative rectification, a half wave rectification is applied with signal inversion “on” or “off”. AUTO rectification uses half wave rectification and automatically inverts the signal on a beat-to-beat basis depending on the maximum amplitude.

FIGURE 3
Real time rhythm strip from the ICD during bicycle stress test with the programmer wand taped to the ICD pocket. The upper tracing shows the channel with the marker annotations (M), the second tracing is a surface ECG lead, the third is the farfield channel from the ICD and the lower tracing is the ventricular intracardiac electrogram (VEGM). During maximal exercise there is sinus tachycardia with CL of 380 ms. The left panel shows T wave oversensing (TWOS) marked with an asterisk (*). The intracardiac electrograms are shortly interrupted during the programming from negative to positive signal rectification. The right panel shows elimination of TWOS (only R waves are sensed by the channel with the marker annotations). Inversion of the VEGM can be observed. At the bottom is a magnification of the VEGM to emphasize the signal inversion from negative to positive rectification.
Abbreviations: CL = cycle length; M = channel with the marker annotations; FF = farfield; VEGM = ventricular intracardiac electrogram; PERM = permanent programming
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282x152mm (300 x 300 DPI)
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